TMDLs for Turley Creek (sediment) and Long Meadow Run (sediment and nitrogen)

Rockingham County, Virginia

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List of Acronyms

BMP	Best Management Practices
BSE	Biological Systems Engineering
CBWM	Chesapeake Bay Watershed Model
COD	Chemical Oxygen Demand
CV	Coefficient of variation
DCR	Virginia Department of Conservation and Recreation
DEQ	Virginia Department of Environmental Quality
DO	Dissolved Oxygen
E&S	Erosion and Sediment Control Program (DCR)
GIS	Geographic Information Systems
LA	Load Allocation
LSC	Local Steering Committee
MDL	Minimum Detection Limit, also Maximum Daily Load
MFBI	Modified Family Biotic Index
MOS	Margin of Safety
MS4	Municipal Separate Storm Sewer System program (EPA)
NASS	National Agricultural Statistics Service (USDA)
NLCD	National Land Cover Dataset
NPS	Non-Point Source
NRCS	Natural Resources Conservation Service (USDA)
PEC	Probable Effect Concentrations
PReP	Pollution Response Program (DEQ)
RBP	Rapid Bioassessment Protocol
RESAC	Mid-Atlantic Regional Earth Science Application Center
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
UAL	Unit-area load, e.g. lbs/acre
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
VSCI	Virginia Stream Condition Index
VPDES	Virginia Pollutant Discharge Elimination System
VSMP	Virginia Stormwater Management Program (DCR)
VT	Virginia Tech
WIP	Watershed Implementation Plan
WLA	Waste Load Allocation

Long Meadow Run and Turley Creek TMDL

Executive Summary

Background

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's Water Quality Planning and Management Regulations require states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQSs). TMDLs represent the total pollutant loading a waterbody can receive without violating WQSs.

Two tributaries of the North Fork of the Shenandoah River in Rockingham County were listed as impaired on Virginia's 2012 Section 303(d) Report on Impaired Waters due to water quality violations of the general aquatic life (benthic) standard. These impaired stream segments are Long Meadow Run (VAV-B45R_LOM01A00) and Turley Creek (VAV-B45R_TRL01A00 and VAV-B45R_TRL02A00). The impairment segment specifics are show in Table ES. 1. The watersheds of the impaired streams are shown in Figure ES.1.

Table ES. 1. Impaired segments addressed in this TMDL report.

Impaired Segment	Size	305(b) Segment ID	Initial Listing Year	Impairment Type
Long Meadow Run	8.53 miles	VAV-B45R_LOM01A00	2008	Benthic
Turley Creek	4.01 miles	VAV-B45R_TRL01A00 and VAV-B45R_TRL02A00	2002	Benthic

This document describes the Total Maximum Daily Loads (TMDLs) for sediment that were developed for Long Meadow Run and Turley Creekwatersheds in order to address the aquatic life water quality impairments.

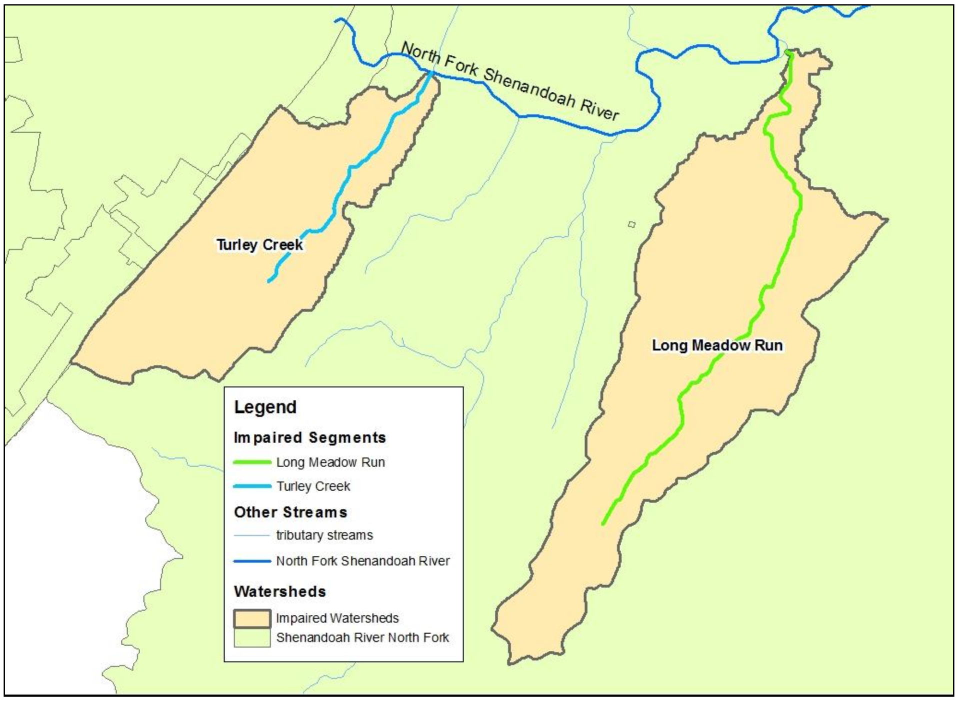

Figure ES. 1. Impaired segments for Long Meadow Run and Turley Creek watersheds.

Pollutant Sources

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressors for each of the impaired watersheds in this study. As a result of the stressor analysis, the most probable stressor contributing to the impairment of the benthic community in Turley Creek was identified as <u>sediment</u> due to the lack of vegetative cover and buffers along the stream in its headwaters, and cattle access through the watershed. In Long Meadow Run, the most probable stressors were identified as <u>nutrients</u>, <u>organic matter</u>, and <u>sediment</u>. Nutrients were identified due to low vegetation scores, high levels of nitrogen in groundwater and the dominance of benthic macroinvertebrates in the biological communities. Phosphorus was determined to be limiting but loads are also minimal, so nitrogen specifically was determined to be the stressor. Nutrients and organic matter are related to each other as stressors, and organic matter was found to be a most probable stressor based on the benthic community metrics. The habitat metrics that were collected as part of the benthic stressor analysis also pointed to sediment as a stressor; especially the embeddedness and bank instability. On an anecdotal note, the diurnal dissolved oxygen sensor was clogged with sediment when deployed by DEQ in Long Meadow Run.

TMDLs were written for the common stressor in both streams, sediment, and also for nitrogen in Long Meadow Run. Additional information and data to support the Benthic Stressor Analysis can be found in Chapter 3 of this report.

Modeling

For the Long Meadow Run and Turley Creek sediment impairments, the procedure used to set TMDL endpoint loads is a modification of the methodology used to address impairments in Maryland's non-tidal watersheds (MDE, 2006, 2009), hereafter referred to as the "all-forest load multiplier" (AllForX) approach. The AllForX approach has previously been approved for use in Virginia by EPA in the Little Otter River and Buffalo Creek sediment TMDLs (Yagow et al., 2015). AllForX is the ratio of modeled loads from the same watershed: the existing condition load divided by the load from an all-forest condition. The AllForX approach was applied locally, using the monitoring stations with impairments and a multiple selection of monitoring stations with healthy biological scores. Separate regressions were developed for each impaired stream and select comparison watersheds between the average Virginia Stream Condition Index (VSCI) biological index scores at individual monitoring stations and the corresponding AllForX ratio from their contributing watersheds and select comparison watersheds. The value of AllForX along each regression line, corresponding to the VSCI impairment threshold value of 60, is the AllForX threshold value which was used to set the TMDL. After the TMDLs were set for each watershed, the Generalized Watershed Loading Functions (GWLF) model was used to simulate sediment loads in both watersheds and nitrogen loads in Long Meadow Run. The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The GWLF model was run in metric units and converted to English units for this report.

Endpoints

AllForX and existing load simulations were performed using GWLF without accounting for existing BMPs. After modeling on individual watersheds was completed, model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of BMPs already implemented within each watershed.

The Sediment TMDLs

The sediment TMDLs for Long Meadow Run and Turley Creek were calculated using Equation ES.1.

$TMDL = WLA_{total} + LA + MOS$ [ES.1]

Where:

WLA_{total} = waste load allocation (point source contributions, including future growth);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

The sediment TMDL load for these watersheds was calculated as the value of AllForX, the point where the regression line between AllForX and the VSCI intersected the VSCI impairment threshold (VSCI = 60), times the all-forest sediment load of the TMDL watershed. The TMDL loads and associated components are shown in Table ES. .

Table ES. 2. Sediment TMDLs and Components (tons/yr) for Long Meadow Run and Turley Creek.

Impairment	TMDL	WLA		LA	MOS
	(tons/yr)				
Cause Code Group B45R-01-BEN					
Long Meadow Run	1,766.4	27.92		1,527.7	210.8
VAV-B45R_LOM01A00		aggregate construction =	10.05 tons/yr		
		aggregate SFH permits =	0.21 tons/yr		
		Future Growth WLA =	17.66 tons/yr		
Cause Code Group B45R-02-BEN					
Turley Creek	926.8	19.87		838.2	68.7
VAV-B45R_TRL01A00		aggregate construction =	3.65 tons/yr		
VAV-B45R_TRL02A00		aggregate ISWGP Permits (VAG840133, VAR050808)	6.86 tons/yr		
		aggregate SFH permits =	0.08 tons/yr		
		Future Growth WLA =	9.27 tons/yr		

Margin of Safety

To allocate loads while protecting the aquatic environment, a margin of safety needs to be considered. An explicit MOS for each TMDL watershed was also calculated using the AllForX method. The 80% confidence interval was developed around the chosen value of AllForX, based on the number of watersheds included in the regression and the standard deviation of their AllForX values. The MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest sediment load for each watershed, amounting to 11.9% of the sediment TMDL for the Long Meadow Run watershed, and 7.4% for the Turley Creek watershed.

Sediment Allocation Scenarios

The target sediment load for each allocation scenario is the TMDL minus the MOS and 1% of the TMDL allocated as a Future Growth WLA. Several allocation scenarios were created for each watershed. Areas of harvested forest and construction are transient sources of sediment subject to existing regulations. Their reduction efficiencies were currently estimated as only half of those possible. Both allocation scenarios assume that these practices will meet their potential reduction efficiencies with better enforcement of existing regulations. The allocation scenario selected by the local Technical Advisory Committee used varying reductions based on relative contribution to the overall sediment load. The selected allocation scenarios are detailed in Table 6-4 and Table 6-5 in this report.

Table ES.3. Sediment TMDL load allocation scenarios for Long Meadow Run.

2007 BMP Load = (tons/yr) 3,624.1

Land Use/ Source Group	Area (acres)	2009 Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Load (tons/yr)	% Reduction	Load (tons/yr)
Row Crops	848.6	481.6	53.4%	224.5	58.0%	202.3
Pasture	5,419.4	2,104.5	53.4%	981.0	58.0%	883.9
Riparian Pasture	139.7	304.4	53.4%	141.9	58.0%	127.9
Hay	1,154.9	299.6	53.4%	139.7	15.5%	253.2
Forest	1,663.7	15.8	0.0%	15.8	0.0%	15.8
Harvested Forest	16.7	1.0	41.3%	0.6	41.3%	0.6
Developed, impervious	37.8	7.8	53.4%	3.6	15.5%	6.6
Developed, pervious	600.2	42.8	53.4%	19.7	15.5%	35.9
Transitional	6.4	16.7	39.8%	10.0	39.8%	10.0
Channel Erosion		1.8	53.4%	0.8	15.5%	1.5
Permitted WLA				0.21		0.21
Total Load		**3,276.06**		**1,537.91**		**1,537.91**

TMDL - MOS - FG = (tons/yr) **1,537.91**

Needed Reduction = (tons/yr) 1,738.15

% Reduction Needed = (%) 53.1%

= WLA components

Permitted VPDES and ISWGP impervious loads were subtracted from "Developed, impervious" loads.
Permitted ISWGP pervious and Septic system loads were subtracted from "Developed, pervious" loads.
Channel erosion reduction credits are distributed proportionately from all land-based sources.

Table ES.4. Sediment TMDL load allocation scenarios for Turley Creek.

2007 BMP Load = (tons/yr) 1,225.1

Land Use/ Source Group	Area (acres)	2009 Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Load (tons/yr)	% Reduction	Load (tons/yr)
Row Crops	220.3	154.2	31.8%	105.2	34.0%	101.76
Pasture	1,673.2	751.6	31.8%	512.9	34.0%	496.02
Riparian Pasture	46.6	125.9	31.8%	85.9	34.0%	83.08
Hay	309.5	76.5	31.8%	52.2	9.2%	69.40
Forest	3,443.8	68.6	0.0%	68.6	0.0%	68.61
Harvested Forest	34.8	4.28	42.9%	2.4	42.9%	2.45
Developed, impervious	11.3	3.0	31.8%	-0.1	9.2%	0.58
Developed, pervious	273.9	20.54	31.8%	9.2	9.2%	13.82
Transitional	2.9	6.3	41.7%	3.7	41.7%	3.65
Channel Erosion		2.8	31.8%	1.9	9.2%	2.55
Permitted WLA				6.9		6.94
Total Load		**1,213.6**		**848.88**		**848.88**

TMDL - MOS - FG = (tons/yr) **848.88**

Needed Reduction = (tons/yr) 364.68

% Reduction Needed = (%) 30.1%

= WLA components

Permitted VPDES and ISWGP impervious loads were subtracted from "Developed, impervious" loads.
Permitted ISWGP pervious and Septic system loads were subtracted from "Developed, pervious" loads.

The Nitrogen TMDL

The nitrogen TMDL for Long Meadow Run watershed was calculated, and its components distributed, using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

$\sum WLA$ = sum of the wasteload (permitted) allocations;

$\sum LA$ = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

Similar to the procedure for sediment, a regression was created between all-forested nitrogen loads and VSCI values for the same set of comparison watersheds. The nitrogen TMDL AllForX threshold was set as the value of AllForX at the point on the regression line where VSCI equals 60, the biological impairment threshold. The nitrogen TMDL load for Long Meadow Run watershed was calculated as the AllForX threshold value times its all-forest nitrogen load.

Table ES.5. Nitrogen TMDLs and Components (tons/yr) for Long Meadow Run.

Impairment	**TMDL**	**WLA**		**LA**	**MOS**
	(lbs/yr)				
Cause Code Group B45R-01-BEN					
Long Meadow Run	19,532.1	520.6		16,866.7	2,144.8
VAV-B45R_LOM01A00		aggregate construction =	20.7 lbs/yr		
		aggregated SFH WLA =	304.6 lbs/yr		
		Future Growth WLA =	195.3 lbs/yr		

Margin of Safety

To allocate loads while protecting the aquatic environment, a margin of safety needs to be considered. An explicit MOS for the Long Meadow Run watershed was also calculated using the AllForX method. The 80% confidence interval was developed around the chosen value of AllForX, based on the number of watersheds included in the regression and the standard deviation of their AllForX values. The MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest nitrogen load for the watershed, amounting to 11.0% of the TMDL for the Long Meadow Run watershed.

Nitrogen Allocation Scenarios

The target load for the allocation scenario in the Long Meadow Run watershed is the TMDL minus the MOS. Both the TMDL and MOS were quantified using the AllForX methodology, discussed in Section 6.2.1. Although groundwater was initially simulated as a separate source to emphasize its important contribution to stream nitrogen loads, in reality the nitrogen in groundwater arises from management practices associated with individual landuses, and can best be reduced through improved management practices on those landuses. In order to make this link more explicit, the groundwater nitrogen load was distributed among the pervious landuses in each watershed based on the simulated ratio of groundwater N to runoff N and the relative area of each landuse.

Two allocation scenarios were created for each watershed. In each scenario, Forest and Permitted WLAs were not subjected to reductions. Areas of harvested forest and construction are transient sources of nitrogen subject to existing regulations. Their reduction efficiencies were currently estimated as only half of those possible. Both allocation scenarios assume that these practices will meet their potential reduction efficiencies with better enforcement of existing regulations. In addition, the first allocation scenario assumed equal percent reductions from all other sources, while in the second scenario, higher reductions were required from the largest land-based sources (Row Crops and Pasture) with lower % reductions from the other sources. Nitrogen allocation scenarios for Long Meadow Run are detailed in Table 6-8.

Table ES.6. Nitrogen TMDL load allocation scenarios for Long Meadow Run.

2007 BMP Load = (lbs/yr) 49,112.9

Land Use/ Source Group	Area (acres)	2009 Nitrogen Load (lbs/yr)	Scenario 1		Scenario 2	
			Reduction	Load (lbs/yr)	Reduction	Load (lbs/yr)
Row Crops	848.6	3,795.9	66.2%	1,284.0	75.0%	949.0
Pasture	5,419.4	27,355.0	66.2%	9,253.2	75.0%	6,838.8
Riparian Pasture	139.7	1,172.2	66.2%	396.5	75.0%	293.1
Hay	1,154.9	5,444.0	66.2%	1,841.5	46.2%	2,930.1
Forest	1,663.7	1,080.9	0.0%	1,080.9	0.0%	1,080.9
Harvested Forest	16.7	38.4	32.9%	25.8	32.9%	25.8
Developed, impervious	37.8	1,014.9	66.2%	343.3	46.2%	546.2
Developed, pervious	600.2	813.2	66.2%	275.1	46.2%	437.7
Transitional	6.4	20.7	0.0%	20.7	0.0%	20.7
Septic Systems						
non-discharging		7,296.5	66.2%	2,365.1	46.2%	3,763.1
permitted				304.6		304.6
Channel Erosion		3.9	66.2%	1.3	46.2%	2.1
Total Load		**48,035.7**		**17,192.0**		**17,192.0**

TMDL - MOS - FG = (lbs/yr) **17,192.0**

Needed Reduction = (lbs/yr) 30,843.7

% Reduction Needed = (%) 64.2%

= WLA components

Permitted ISWGP impervious loads were subtracted from "Developed, impervious" loads.

Permitted ISWGP pervious loads were subtracted from "Developed, pervious" loads.

Pre-2009 channel erosion reduction credits were distributed proportionately from all land-based sources.

Future Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairments on Turley Creek and Long Meadow Run. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by State Water Control Board (SWCB) and then by the USEPA measures must be taken to reduce pollutant levels in the stream. These measures, which can include the use of better treatment technology and the installation of BMPs, are implemented in an iterative process that is described along with specific BMPs in the Implementation Plan. The process for developing an Implementation Plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of Implementation Plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved Implementation Plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

DCR and DEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable Implementation Plan that will result in meeting the water quality target. Stream delisting of Turley Creek and Long Meadow Run will be based on biological health and not on numerical pollution loads.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Technical Advisory Committee (TAC) meetings and public meetings were organized for this purpose. During the original timeframe of this project, a total of two public meetings and three TAC meetings took place from November 2011 until March 2012. Since the original TMDL was rejected by EPA, another series of meetings was held during the current revision phase to re-open the TMDL starting in June 2014 in order to address EPA comments and to re-submit the TMDL. A series of four TAC meetings took place until the project was culminated at a public meeting held on September 14, 2015.

Chapter 1: **INTRODUCTION**

1.1. Background

1.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2. Impairment Listing

The subjects of this TMDL study are two neighboring impaired stream segments in Turley Creek and Long Meadow Run. These impaired segments are located within the North Fork Shenandoah River Basin within Rockingham County in the Commonwealth of Virginia, Figure 1-1.

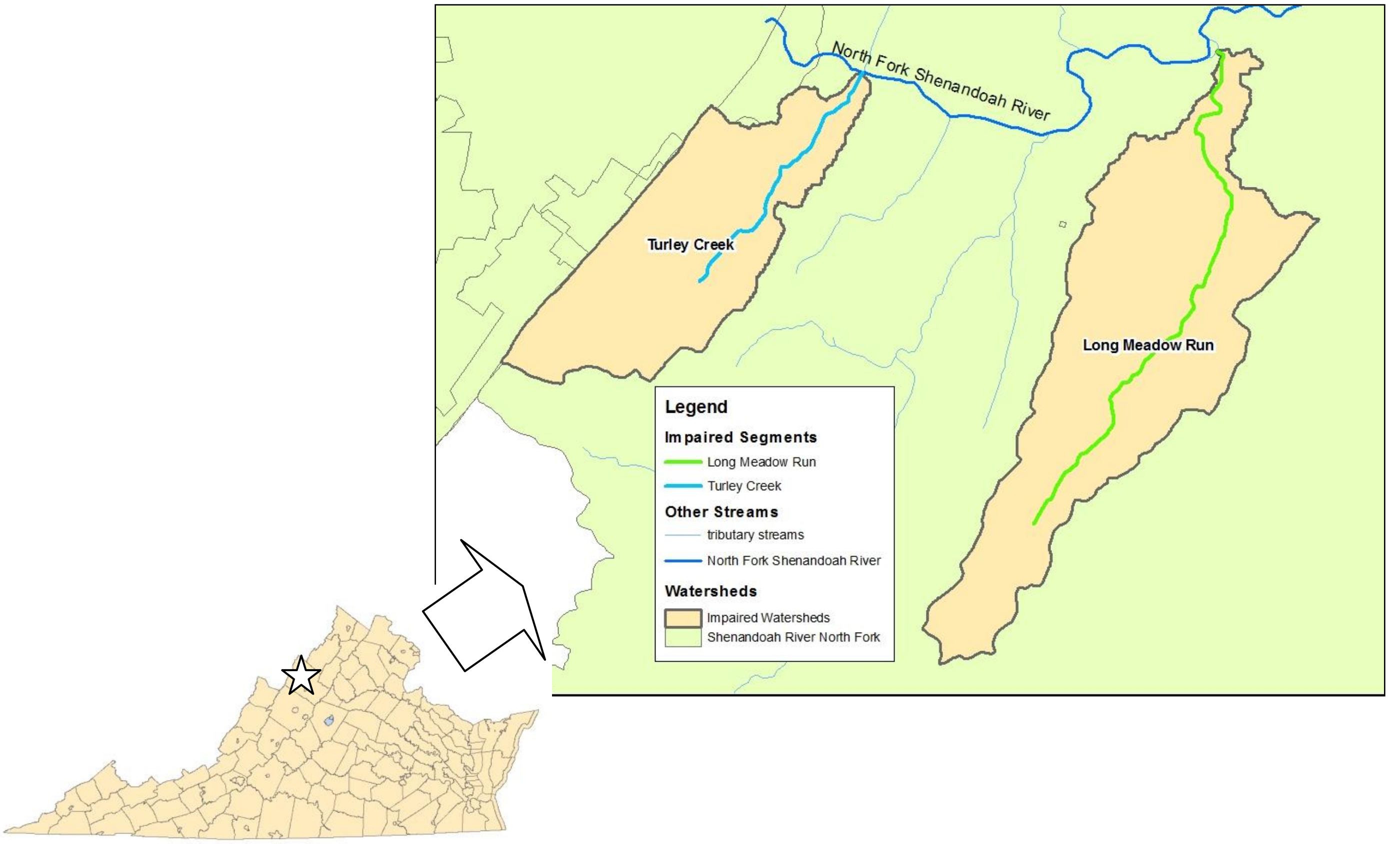

Figure 1-1. Location of Impaired Segments and Watersheds

Turley Creek and Long Meadow Run were originally listed as impaired on Virginia's Section 305(b) Total Maximum Daily Load Priority Report (Turley in 2002; Long Meadow in 2008), due to water quality violations of the general aquatic life (benthic) standard. As a result, Virginia entered into an agreement with the Environmental Protection Agency (EPA) to write a TMDL by 2014.

The Virginia Department of Environmental Quality (DEQ) has delineated the benthic impairment as 4.01 miles on Turley Creek (stream segments VAV-B45R_TRL01A00 and VAV-B45R_TRL02A00) and 8.53 miles on Long Meadow Run (stream segment VAV-B45R_LOM01A00). The Turley Creek impairment begins in its headwaters and extends downstream to its confluence with the North Fork Shenandoah River. The Long Meadow Run impaired segment begins in the headwaters and extends downstream to its confluence with the North Fork Shenandoah River.

The DEQ 2012 Fact Sheets for Category 5 Waters (VADEQ, 2012) state that Turley Creek and Long Meadow Run are impaired based on assessments at biological stations 1BTRL000.02 and 1BLOM000.24, respectively. The source of impairment in both Turley Creek and Long Meadow Run was considered "Unknown."

1.1.3. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to a violation of the benthic standard. A violation of this standard is assessed on the basis of measurements of the in-stream benthic macro-invertebrate community. Water bodies having a benthic impairment are not fully supportive of the aquatic life designated use for Virginia's waters.

1.2. Designated Uses and Applicable Water Quality Standards

1.2.1. Designation of Uses (9 VAC 25-260-10)

> "A. All state waters are designated for the following uses: recreational uses (e.g. swimming and boating); the propagation and growth of a balanced indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)." SWCB, 2010.

1.2.2. General Standard (9 VAC 25-260-20)

The general standard for a water body in Virginia is stated as follows:

> "A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.
>
> Specific substances to be controlled include, but are not limited to: floating debris, oil scum, and other floating materials; toxic substances (including those which bioaccumulate); substances that produce color, tastes, turbidity, odors, or settle to form sludge deposits; and substances which nourish undesirable or

> nuisance aquatic plant life. Effluents which tend to raise the temperature of the receiving water will also be controlled." SWCB, 2010.

The biological monitoring program in Virginia that is used to evaluate compliance with the above standard is run by the Virginia Department of Environmental Quality (DEQ). Evaluations of monitoring data from this program focus on the benthic (bottom-dwelling) macro (large enough to see) invertebrates (insects, mollusks, crustaceans, and annelid worms) and are used to determine whether or not a stream segment has a benthic impairment. Changes in water quality generally result in alterations to the quantity and diversity of the benthic organisms that live in streams and other water bodies. Besides being the major intermediate constituent of the aquatic food chain, benthic macro-invertebrates are "living recorders" of past and present water quality conditions. This is due to their relative immobility and their variable resistance to the diverse contaminants that are introduced into streams. The community structure of these organisms provides the basis for the biological analysis of water quality. Both qualitative and semi-quantitative biological monitoring have been conducted by DEQ since the early 1970's. The U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocol (RBP) II was employed beginning in the fall of 1990 to utilize standardized and repeatable assessment methodology (Barbour et al., 1999). For any single sample, the RBP II produces water quality ratings of "non-impaired," "slightly impaired," "moderately impaired," or "severely impaired." In Virginia, benthic samples are typically collected and analyzed twice a year in the spring and in the fall.

The RBP II procedure evaluates the benthic macro-invertebrate community by comparing ambient monitoring "network" stations to "reference" sites. A reference site is one that has been determined to be representative of a natural, non-impaired water body. The RBP II evaluation also accounts for the natural variation noted in streams in different eco-regions. One additional product of the RBP II evaluation is a habitat assessment. This is a stand-alone assessment that describes bank condition and other stream and riparian corridor characteristics and serves as a measure of habitat suitability for the benthic community.

Beginning in 2006, DEQ switched their bioassessment procedures. While the RBP II protocols were still followed for individual metrics, a new index, the Virginia Stream Condition Index (VSCI), was developed based on comparison of observed data to a set of reference conditions, rather than with data from a reference station. The new index was also calculated for all previous samples in order to better assess trends over time.

Determination of the degree of support for the aquatic life designated use is based on biological monitoring data and the best professional judgment of the regional biologist, relying primarily on the most recent data collected during the current 5-year assessment period. In Virginia, any stream segment with an overall rating of “moderately impaired” or “severely impaired” is placed on the state’s 303(d) list of impaired streams (VADEQ, 2002).

Chapter 2: WATERSHED CHARACTERIZATION

2.1. Water Resources

The Turley Creek watershed and the Long Meadow Run watershed are part of the Potomac and Shenandoah River basin, and part of state hydrologic unit B45 (National Watershed Boundary Datasets PS55 and PS57, respectively). Turley Creek and Long Meadow Run are located north of Harrisonburg on US Route 613 and US Route 259 respectively, in Rockingham County, Virginia. Turley Creek and Long Meadow Run both flow northeast and discharge into the North Fork Shenandoah River (USGS Hydrologic Unit 02070006). The North Fork Shenandoah River is a tributary of the Potomac River Basin, which flows into the Chesapeake Bay.

Long Meadow Run and Turley Creek watersheds lie in an area of karst topography. Karst watersheds often contain stream segments that lose water as they flow downstream. The water infiltrates into the ground recharging the local groundwater, because the water table is below the bottom of the stream channel. Flow from losing streams may disappear from the surface channel at some times and in some reaches during the year, only to re-emerge as surface flow further downstream.

2.2. Eco-region

The Turley Creek watershed is located entirely within the Northern Sandstone Ridges sub-division, of the Ridge and Valley ecoregion while the Long Meadow Run watershed is located entirely within the Northern Limestone/Dolomite Valleys sub-division, of the Ridge and Valley ecoregion. The Ridge and Valley ecoregion is primarily ridges and lowland valleys and is composed of sandstone, shale, conglomerate and coal, with numerous springs and caves. The ecoregion has a diversity of aquatic habitats and species of fish (USEPA, 2002).

2.3. Soils and Geology

The Turley Creek watershed is comprised of soils primarily in the Frederick (59%) and Weikert (15%) series, while the Long Meadow Run watershed contains predominantly soils in the Frederick series (92%). These series form various complexes, many with rock outcrops. The Frederick series (fine, mixed, semiactive, mesic Typic Paleudults) consists of very deep well drained soils with moderate permeability. These soils formed in residuum derived mainly from dolomitic limestone with interbeds of sandstone, siltstone, and shale. This soil type is typically found on slope ranges from 0 to 60 percent. The Weikert series (Loamy-skeletal, mixed, active, mesic Lithic Dystrudepts) consists of very shallow, well drained soils of moderately rapid permeability and are formed in material that weathered from interbedded gray and brown acid shale, siltstone, and fine-grained sandstone on gently sloping to very steep areas on uplands. This soil type is found on a wide range of slopes from 0 to 100 percent (USDA-NRCS, 2010).

2.4. Climate

Climate data for the Turley Creek and Long Meadow Run watersheds were summarized from meteorological observations made by the Cootes Store National Climatic Data Center station (441986) located within Rockingham County, Virginia approximately 0.5 miles west of the Turley creek outlet and 5.6 miles west of the Long Meadow Run outlet. Average annual precipitation at this station is 33.55 inches. Average annual daily temperature at the Cootes Store station is 56.0°F. The highest average daily temperature of 90.1°F occurs in July while the lowest average daily temperature of 21.9°F occurs in January, as obtained from the 1940-2012 period of record (SERCC, 2012). For the modeling simulations, unique precipitation and temperature time-series were created at the centroid of each watershed from the Climate Forecast System Reanalysis (CFSR) project (cfsr.bse.vt.edu).

2.5. Existing Land Use

Land use categories for the Turley Creek and Long Meadow Run watersheds were derived from the 2009 cropland data layer developed by the USDA National Agricultural Statistics Service (NASS). The NASS data are available online and were developed from USDA National Resources Inventory data in agricultural areas and supplemented with 2006 National Land Classification Data (NLCD) in non-agricultural areas. The distribution of land use acreages in the watershed is given in Table 2-1, and shown in Figure 2-1. The Long Meadow Run watershed is 9,889.1 acres in size. The main land use category in the watershed is pasture (53% of the watershed), followed by forest (17%), hay (13%), and the remainder in cropland, residential or developed land uses. The Turley Creek watershed is 6,029.0 acres in size. The main land use categories in the watershed are forest (58% of the watershed) and pasture (27%). The remainder is in hay, cropland, residential or developed land uses. The pasture/hay categories were combined and assigned as 85% pasture and 15% hay, based on professional judgment by local NRCS personnel (02/13/12).

Table 2-1. NASS Land Use Summary in Turley Creek and Long Meadow Run (acres)

NASS Landuse Categories	Lower Long Meadow Run	Upper Long Meadow Run	Unnamed Tributary	Long Meadow Run Total	Lower Turley Creek	Upper Turley Creek	Brock Creek	Turley Creek Total
	Area in acres				Area in acres			
Corn	60.7	602.0	216.9	879.6	81.7	101.5	20.5	203.8
Soybeans	6.2	44.0	37.0	87.2	5.4	10.8	0.8	17.0
Barley	-	7.0	2.3	9.3	3.9	-	-	3.9
Winter Wheat	-	14.7	-	14.7				-
Rye	-	11.6	-	11.6				-
Alfalfa	13.2	27.8	5.4	46.5	4.9	-	0.8	5.7
Other Pasture/Hays	362.2	4,595.7	1,498.9	6,456.8	485.6	805.2	628.3	1,919.1
Pasture/Grass	1.0	37.3	12.0	50.2	16.3	13.6	68.6	98.5
NLCD - Open Water	1.6	-	-	1.6	1.9	-	10.8	12.7
NLCD - Developed/Open Space	18.4	336.7	125.7	480.8	35.3	87.1	110.9	233.3
NLCD - Developed/Low Intensity	6.1	106.0	34.2	146.4	9.9	8.1	22.9	40.9
NLCD - Developed/Medium Intensit	1.0	12.2	2.6	15.8	-	0.8	3.1	3.9
NLCD - Developed/High Intensity	-	0.8	-	0.8	-	-	1.5	1.5
NLCD - Barren	0.6	-	-	0.6	-	-	8.5	8.5
NLCD - Deciduous Forest	4.7	1,214.7	272.6	1,491.9	340.8	343.3	2,517.4	3,201.4
NLCD - Evergreen Forest	1.2	116.4	30.4	148.0	44.2	67.4	128.6	240.3
NLCD - Mixed Forest	-	24.3	3.1	27.4	6.0	12.6	18.3	36.9
Dbl. Crop Barley/Corn	-	16.7	-	16.7	0.8	0.8	-	1.5
Dbl. Crop Barley/Soybeans	-	3.1	-	3.1				-
Total	477.0	7,170.9	2,241.2	**9,889.1**	1,036.6	1,451.3	3,541.1	**6,029.0**

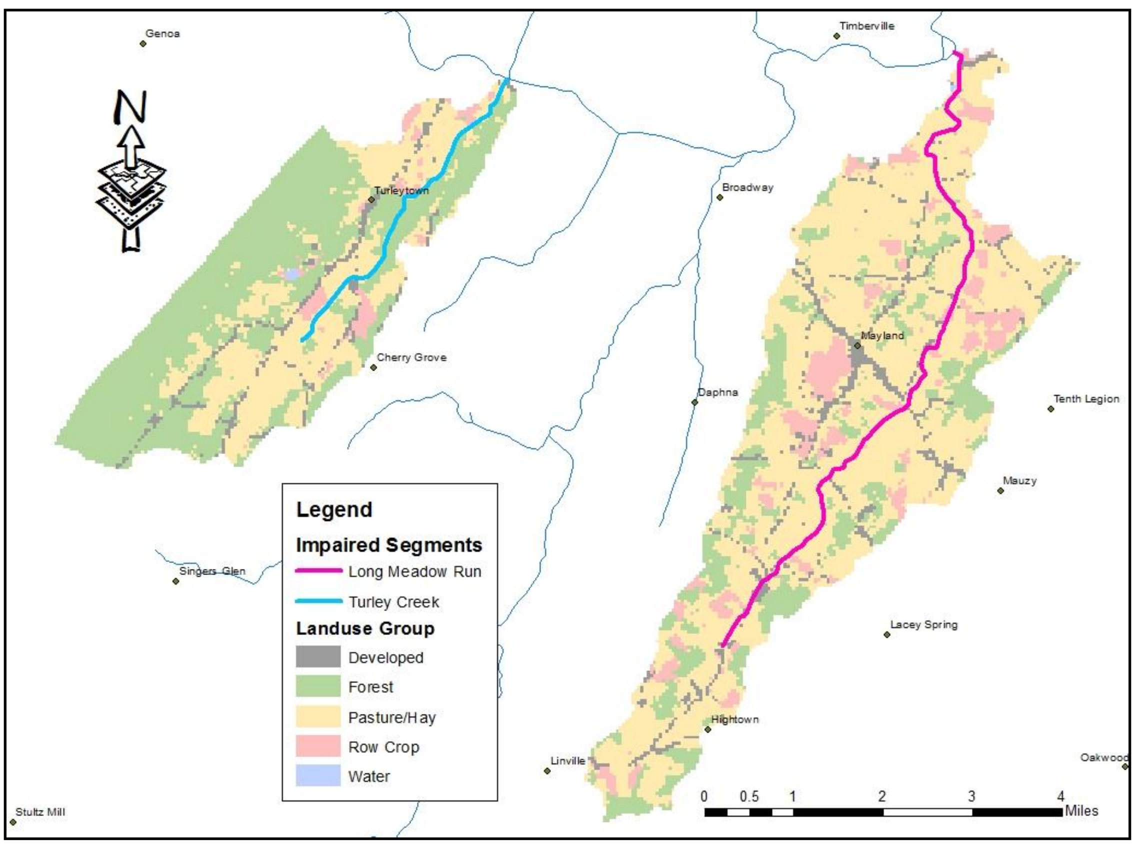

Figure 2-1. NASS Generalized Land Use in Turley Creek and Long Meadow Run Watersheds

2.6. Biological Monitoring Data

Biological monitoring consisted of sampling the benthic macro-invertebrate community along with corresponding habitat assessments. The data for the bioassessments in Turley Creek and Long Meadow Run were based on DEQ biological monitoring at one DEQ monitoring site in each watershed. The biological monitoring station on Turkey Creek (1BTRL000.02) was monitored 23 times between 1996 and 2014. The biological monitoring station on Long Meadow Run (1BLOM000.24) was monitored 22 times between 1996 and 2014. In addition, after the beginning of the TMDL study, 5 benthic macro-invertebrate samples were taken on the main tributary to Turley Creek, Brock Creek (1BBRO000.34), which remains healthy. The locations of the DEQ biological and ambient monitoring stations in the Turley Creek and Long Meadow Run watersheds are shown in Figure 2-2.

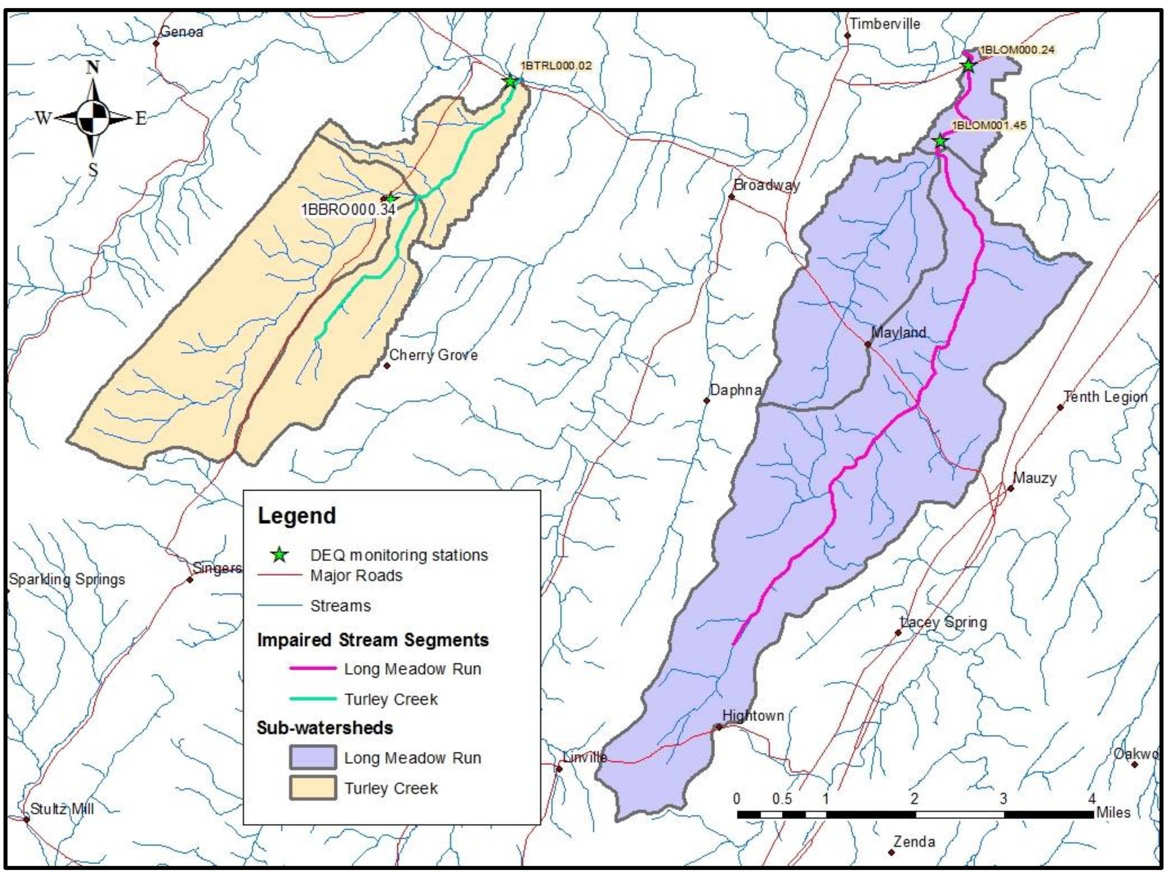

Figure 2-2. Locations of DEQ Monitoring Stations in the Turley Creek and Long Meadow Run Watersheds

Biological samples were collected from a cross-section of the stream channel, but focused primarily on the riffle environment. The organisms in each sample were separated out into identifiable family or species, and then a count was made of the number of organisms in each taxa. A full listing of the benthic macroinvertebrate taxa inventory or distribution within each biological sample is given for Turley Creek in Table 2-2, and for Long Meadow Run in Table 2-3.

Table 2-2. Taxa Inventory by Sample Date in Turley Creek (TRL)

				1BTRL000.02																						
Family/ Genus	Functional Family Group	Tolerance Value	Habit	05/30/96	10/16/96	05/29/97	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	10/02/01	05/03/06	10/09/07	03/24/08	03/27/09	10/13/09	10/12/10	04/27/11	11/08/11	04/30/12	10/18/12	03/20/13	04/14/14	11/10/14
Glossosomatidae	Scraper		clinger			5																		1		
Leuctridae	Shredder		#N/A	2		4								1												
Rhyacophilidae	Predator		clinger									1					1									1
Capniidae	Shredder	1	#N/A					1		1													1			
Ephemerellidae	Collector	1	clinger	8		2		1	36	4	3	23	4	16		16	34	6	3	3	1				11	26
Perlidae	Predator	1	clinger	5	1			1							1									1	1	
Stenelmis	Scraper	1	#N/A																	56	6	6	3			
Amphinemura	Shredder	2	#N/A																					2		
Athericidae	Predator	2	sprawler						2																	
Baetis	Collector	2	#N/A																			5	3			
Ephemerella	Collector	2	#N/A																	4		3		1		
Isonychia	Filterer	2	#N/A																	1	1	2	7			
Isonychiidae	Filterer	2	swimmer				24	6	2	3	1	7	5	1			2	1	2						4	2
Leptophlebiidae	Collector	2	swimmer	6		2																			1	
Nemouridae	Shredder	2	sprawler						1					1										47		
Peltoperlidae	Shredder	2	clinger			5																				
Promoresia	Scraper	2	#N/A																	4	1	1	1			
Psychomyiidae	Collector	2	clinger															1								1
Chimarra	Filterer	3	#N/A																		15	2	5	2		
Hydrobiidae	Scraper	3	#N/A	1																				2		
Hydropsychidae	Filterer	3	clinger	4	2	1	72	38	35	13	2	34	37	4	53	21	46	28	22		3		12		6	33
Philopotamidae	Collector	3	clinger			1	19	45	4	25	2	27	13	2	16	4	21	34	16					1	3	5
Psychomyia	Scraper	3	#N/A																		1					
Simulium	Filterer	3	#N/A																			1	7	1		
Tipulidae	Shredder	3	burrower	2		2	1	3	1	2	6			2	1	2	6	4	1						3	3
Acentrella	Collector	4	#N/A																			4				
Antocha	Collector	4	#N/A																		2	2	2			
Baetidae	Collector	4	swimmer	4	23	21	3		1	2	16		11	2	5	1		2	2			8			3	
Caenidae	Collector	4	sprawler							5			4				1		2							
Elmidae	Collector	4	clinger	17	2	2	2	4	15	11	8	26	16	47	9		24	11	43		1			3	23	24
Heptageniidae	Scraper	4	clinger	1	1	4	18	13	12	6	4	18	7	1	3	5	11	3	3				2	4	2	4
Leptohyphidae	Collector	4	sprawler	17																				3		
Optioservus	Scraper	4	#N/A																	6	4	9	1	4		
Psephenidae	Scraper	4	clinger							1		1					1	1	9						1	
Psephenus	Scraper	4	#N/A															2	1	3						
Stenacron	Scraper	4	#N/A																				2	2		
Tipula	Shredder	4	#N/A																				2			
Branchiobdellidae	Collector	5	#N/A	1																						
Cambaridae	Shredder	5	#N/A	1			1						1													
Corydalidae	Predator	5	clinger	1			1			1		1							1							
Hydracarina (unknown)	Predator	5	#N/A	1		5	1								1		1								2	
Plauditus		5	#N/A																			4	1			
Cheumatopsyche	Filterer	6	#N/A																	4	35	11	34			
Chironomidae (A)	Collector	6	#N/A	22	51	55	10	12	61	23	103	5	3	27	5	44	57	13	4	18	10	31	8	1	37	8
Empididae	Predator	6	sprawler								1	1		3			3		2					1	1	
Simuliidae	Filterer	6	clinger		14	30		2	5	6	44	1	5	3	2	4	3	1							8	
Veliidae	Predator	6	#N/A						1															1		
Planorbidae	Scraper	7	#N/A							3																
Prosimulium	Filterer	7	#N/A																			3				
Asellidae	Collector	8	sprawler	1									1	13	5		1	1				2				1
Lumbriculidae	Collector	8	#N/A	3	2																					
Tricladida (unknown)	Collector	8	#N/A			1				3					1										1	2
Chironomidae (B)	Collector	9	burrower	7	3	2																		1		
Coenagrionidae	Predator	9	climber							1		1														
Naididae	Collector	9	burrower								1						2			5					3	
Ephemeroptera (unknown)	Collector	(blank)	#N/A															1						1		
Hydropsyche/Ceratopsyche	Filterer	(blank)	#N/A																		21	5	9			
Maccaffertium		(blank)	#N/A																	6	5	2	8			
Teloganopsis deficiens		(blank)	#N/A																		2	6	2			
		No. of Species*:		19	9	16	11	11	13	17	12	13	12	14	12	8	16	14	13	11	16	20	19	19	17	12
		Abundance:		104	99	142	152	126	176	110	191	146	107	123	102	97	214	107	110	109	109	110	110	79	110	110

Additional Benthic Metrics

Scraper/Filterer	0.5	0.1	0.3	0.2	0.3	0.3	0.5	0.1	0.5	0.1	0.1	0.1	0.2	0.2	NA	0.5	13.6	0.2	0.8	0.1	4.3	0.2	0.1
%Filterer-Collector	87%	98%	82%	86%	86%	90%	86%	94%	84%	93%	93%	94%	93%	89%	93%	85%	32%	82%	72%	79%	18%	91%	93%
% Haptobenthos	35%	20%	35%	74%	83%	61%	61%	33%	90%	77%	59%	82%	52%	66%	79%	88%	3%	5%		13%	13%	50%	85%
% Shredder	5%		8%	1%	3%	1%	3%	3%		1%	3%	1%	2%	3%	4%	1%				3%	62%	3%	3%

- Dominant 2 species in each sample.

* - An additional 10 species were present in a single sample over the period of record.

Table 2-3. Taxa Inventory by Sample Date in Long Meadow Run (LOM)

				1BLOM000.24																			
Family/ Genus	Functional Family Group	Tolerance Value	Habit	06/05/96	10/16/96	05/29/97	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	11/17/03	11/07/05	05/03/06	03/26/08	03/27/09	09/13/10	03/22/11	11/08/11	04/30/12	10/22/12	03/20/13
Stenelmis	Scraper	1	#N/A															1	6	3	5	11	7
Promoresia	Scraper	2	#N/A																			1	1
Chimarra	Filterer	3	#N/A																			6	1
Hydropsychidae	Filterer	3	clinger			4	8	16	2	1	20	4	10	65	12	9	6			5	5		
Philopotamidae	Collector	3	clinger				1	2		22	15	16		2									
Simulium	Filterer	3	#N/A																			2	1
Tipulidae	Shredder	3	burrower	1	1	3				2		1		2									
Baetidae	Collector	4	swimmer		5	5	2	8	1				19		1								
Dubiraphia	Collector	4	#N/A																1				1
Elmidae	Collector	4	clinger		6		4	9	11	37	17	21	12	14	23	27	17			1			
Heptageniidae	Scraper	4	clinger						3														
Optioservus	Scraper	4	#N/A															1		1		7	
Pleuroceridae	Scraper	4	clinger	10	17	25	27	18	5	10	1	7	10	23	4	3	4						
Psephenidae	Scraper	4	clinger		1					1			4										
Tipula	Shredder	4	#N/A																		1	2	1
Cambaridae	Shredder	5	#N/A		2	3	1																
Hydracarina (unknown)	Predator	5	#N/A			1										5							
Pleuroceridae		5	clinger																3	6		11	3
Tricladida	Collector	5	#N/A															5	4	5		13	1
Ancylidae	Scraper	6	clinger									1		1			1						
Cheumatopsyche	Filterer	6	#N/A																	3	3	1	
Chironomidae (A)	Collector	6	#N/A	30	4	45	4	1	164	39	220	32	39	16	26	9	5		22	7	28	18	72
Crangonyctidae		6	swimmer																	1		2	3
Empididae	Predator	6	sprawler					1				2	2			1							
Gammaridae	Collector	6	swimmer		13			1			7	5	1	1									
Hydracarina		6	#N/A																		1		1
Simuliidae	Filterer	6	clinger	32	10	14					14		34		3	1	1						
Asellidae	Collector	8	sprawler	15	26	21	72	59	25	22	24	26	8	100	36	37	65	96	64	29	63	117	16
Lumbriculidae	Collector	8	#N/A	4	2			1								4							
Physidae	Scraper	8	#N/A								10												
Sphaeriidae	Filterer	8	sprawler				1	2					4		1								
Tricladida (unknown)	Collector	8	#N/A	5	9	2	2			1		2	1	5	2	2	8						
Chironomidae (B)	Collector	9	burrower	10	1	2																	
Coenagrionidae	Predator	9	climber								2												
Naididae	Collector	9	burrower						9			1		1								1	
Tubificidae	Collector	9	burrower	2		1	4		1	6		4	5	1		4	2	7	6	38	3	17	
Hydropsyche/Ceratopsyche	Filterer	(blank)	#N/A																4	10	1	10	2
		No. of Species*:		9	13	12	11	11	9	10	10	13	13	12	9	11	9	5	8	12	9	15	13
		Abundance:		109	97	126	126	118	221	141	330	122	149	231	108	102	109	110	110	109	110	219	110
		Additional Benthic Metrics																					
		Scraper/Filterer		0.3	1.8	1.4	3.0	1.0	4.0	11.0	0.3	2.0	0.3	0.4	0.3	0.3	0.7	NA	1.5	0.2	0.6	1.0	2.0
		%Filterer-Collector		90%	78%	75%	78%	84%	96%	91%	96%	91%	89%	89%	96%	91%	95%	98%	92%	90%	94%	84%	85%
		% Haptobenthos		14%	28%	17%	58%	52%	13%	32%	12%	34%	8%	44%	33%	36%	60%	93%	62%	35%	61%	65%	17%
		% Shredder		1%	3%	5%	1%			1%		1%		1%							1%	1%	1%

- Dominant 2 species in each sample.

* - An additional 15 species were present in a single sample over the period of record.

DEQ has recently upgraded its biomonitoring and biological assessment methods to those currently recommended by USEPA Region 3 for the mid-Atlantic region. As part of this effort, a study was performed to assist the agency in moving from a paired-network/reference site approach based on the RBP II to a regional reference condition approach, and has led to the development of the Virginia Stream Condition Index (VSCI) for Virginia's non-coastal areas (Tetra Tech, 2003). This multi-metric index is based on 8 biomonitoring metrics, with a scoring range of 0-100, that include some different metrics than those used previously in the RBP II, but are based on the same taxa inventory. A maximum score of 100 represents the best benthic community sites. The current proposed threshold criteria would define "non-impaired" sites as those with a VSCI of 60 or above, and "impaired" sites as those with a score below 60 (VADEQ, 2006). The VSCI scores for Turley Creek are shown in Table 2-4, and for Long Meadow Run in Table 2-5.

Table 2-4. Virginia Stream Condition Index (VSCI) Scores for Turley Creek (TRL)

StationID	1BTRL000.02																							
CollDate	05/30/96	10/16/96	05/29/97	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	10/02/01	05/03/06	10/09/07	03/24/08	03/27/09	03/27/09	10/13/09	10/12/10	04/27/11	11/08/11	04/30/12	10/18/12	03/20/13	04/14/14	11/10/14
RepNum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1
Individual VSCI Raw Metric Values																								
Richness Score	22	9	16	12	11	13	19	13	13	12	14	12	8	14	12	13	13	8	11	12	11	20	17	12
EPT Taxa	9	4	9	6	7	7	8	6	6	7	8	5	5	6	6	7	7	4	6	6	7	8	8	7
%Ephemeroptera	33.6	24.2	20.4	29.4	15.9	29.0	17.9	12.5	32.9	29.0	16.3	7.8	22.7	21.8	23.1	12.1	10.9	12.7	8.2	30.9	22.7	15.5	19.1	29.1
%PT - Hydropsychidae	7.5	1.0	10.6	13.1	37.3	2.8	23.2	1.0	19.2	12.1	3.3	16.7	4.1	14.5	5.8	32.7	14.5		14.5	1.8	5.5	6.4	3.6	6.4
%Scrapers	17.8	3.0	7.7	13.1	13.5	15.3	18.8	6.3	30.8	21.5	39.0	11.8	5.2	17.3	16.3	14.0	50.0	68.2	16.4	19.1	15.5	10.0	23.6	25.5
%Chironomidae	27.1	54.5	40.1	6.5	9.5	34.7	20.5	53.6	3.4	2.8	22.0	4.9	45.4	20.0	33.7	12.1	3.6	16.4	9.1	28.2	7.3	42.7	33.6	7.3
%2 Dominant	36.4	74.7	59.9	62.7	65.9	55.1	42.9	76.6	41.8	49.5	60.2	67.6	67.0	40.0	56.7	57.9	59.1	77.3	67.3	47.3	60.9	62.7	54.5	53.6
Modified Family Biotic Index	4.7	5.6	5.0	4.6	4.3	5.1	4.7	5.5	4.3	4.7	4.9	5.2	5.4	4.7	5.1	4.4	4.3	4.6	5.1	4.9	5.0	5.4	4.9	4.7
Individual VSCI Metric Scores																								
Richness Score	100.0	40.9	72.7	54.5	50.0	59.1	86.4	59.1	59.1	54.5	63.6	54.5	36.4	63.6	54.5	59.1	59.1	36.4	50.0	54.5	50.0	90.9	77.3	54.5
EPT Taxa Score	81.8	36.4	81.8	54.5	63.6	63.6	72.7	54.5	54.5	63.6	72.7	45.5	45.5	54.5	54.5	63.6	63.6	36.4	54.5	54.5	63.6	72.7	72.7	63.6
%Ephem Score	54.9	39.5	33.3	48.0	25.9	47.3	29.1	20.4	53.6	47.3	26.5	12.8	37.0	35.6	37.6	19.8	17.8	20.8	13.3	50.4	37.1	25.2	31.1	47.5
%PT-H Score	21.0	2.8	29.7	36.7	100.0	8.0	65.2	2.9	53.9	34.1	9.1	46.8	11.6	40.9	16.2	91.9	40.9	0.0	40.9	5.1	15.3	17.9	10.2	17.9
%Scraper Score	34.4	5.9	15.0	25.3	26.1	29.7	36.3	12.1	59.7	41.7	75.6	22.8	10.0	33.5	31.7	27.2	96.9	100.0	31.7	37.0	30.0	19.4	45.8	49.3
%Chironomidae Score	72.9	45.5	59.9	93.5	90.5	65.3	79.5	46.4	96.6	97.2	78.0	95.1	54.6	80.0	66.3	87.9	96.4	83.6	90.9	71.8	92.7	57.3	66.4	92.7
%2 Dominant Score	91.8	36.5	58.0	53.8	49.3	64.9	82.6	33.9	84.1	72.9	57.6	46.8	47.7	86.7	62.5	60.8	59.1	32.8	47.3	76.2	56.5	53.9	65.7	67.0
%MFBI Score	77.8	65.4	73.9	78.9	83.8	72.4	78.5	65.6	83.9	78.3	74.6	70.2	68.2	77.4	72.0	81.9	83.4	79.9	72.5	74.6	73.0	67.5	74.5	78.1
VSCI*	**66.8**	**34.1**	**53.0**	**55.7**	**61.2**	**51.3**	**66.3**	**36.9**	**68.2**	**61.2**	**57.2**	**49.3**	**38.9**	**59.0**	**49.4**	**61.5**	**64.6**	**48.7**	**50.1**	**53.0**	**52.3**	**50.6**	**55.5**	**58.8**

- Primary biological effects.

* - VSCI Rating: VSCI > 60 (Healthy); VSCI ≤ 60 (Impaired).

Table 2-5. Virginia Stream Condition Index (VSCI) Scores for Long Meadow Run (LOM)

StationID	1BLOM000.24																								
CollDate	06/05/96	10/16/96	05/29/97	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	11/17/03	11/07/05	11/07/05	05/03/06	03/26/08	03/27/09	04/15/10	09/13/10	03/22/11	11/08/11	04/30/12	10/22/12	10/22/12	03/20/13	06/03/14	11/10/14
RepNum	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1
Individual VSCI Raw Metric Values																									
TotTaxa	9	13	14	12	11	12	11	11	15	14	10	10	10	11	9	6	4	7	9	7	12	11	11	6	10
EPTTax		1	4	3	3	3	2	2	2	3	2	2	2	1	1			1	1	1	2	2	2	0	1
%Ephem	0.0	5.2	5.5	1.6	6.8	1.8	0.0	0.0	0.0	12.7	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%PT - Hydropsychidae				0.8	1.7		15.5	4.5	12.9	0.7	0.8	1.0									0.9	4.5	0.9	0.0	0.0
%Scrap	9.2	24.7	19.5	24.4	22.9	8.5	33.8	8.5	23.4	17.3	13.0	20.8	24.8	29.4	20.2	8.7	1.8	9.1	10.0	4.5	10.9	16.4	10.9	9.1	15.5
%Chiro	36.7	5.2	36.7	3.1	0.8	73.2	27.5	66.5	25.8	26.0	8.4	5.0	23.9	8.8	4.6	18.3	0.0	20.0	6.4	25.5	10.0	6.4	65.5	0.0	7.3
%2Dom	56.9	44.3	54.7	78.0	65.3	84.4	53.5	73.7	46.8	48.7	73.3	68.3	56.9	62.7	75.2	85.6	93.6	78.2	60.9	82.7	73.6	56.4	80.0	92.7	71.8
HBI	6.6	6.1	5.8	6.8	6.4	6.2	5.3	6.0	5.7	5.7	6.7	6.4	6.2	6.4	7.0	7.2	8.1	7.3	7.8	7.1	7.2	7.0	6.0	7.5	7.3
Individual VSCI Metric Scores																									
Richness Score	40.9	59.1	63.6	54.5	50.0	54.5	50.0	50.0	68.2	63.6	45.5	45.5	45.5	50.0	40.9	27.3	18.2	31.8	40.9	31.8	54.5	50.0	50.0	27.3	45.5
EPT Score	0.0	9.1	36.4	27.3	27.3	27.3	18.2	18.2	18.2	27.3	18.2	18.2	18.2	9.1	9.1	0.0	0.0	9.1	9.1	9.1	18.2	18.2	18.2	0.0	9.1
%Ephem Score	0.0	8.4	8.9	2.6	11.1	2.9	0.0	0.0	0.0	20.7	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%PT-H Score	0.0	0.0	0.0	2.2	4.8	0.0	43.5	12.7	36.2	1.9	2.1	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	12.8	2.6	0.0	0.0
%Scraper Score	17.8	48.0	37.9	47.3	44.3	16.4	65.5	16.4	45.3	33.6	25.1	40.3	48.0	57.0	39.1	16.8	3.5	17.6	19.4	8.8	21.1	31.7	21.1	17.6	30.0
%Chironomidae Score	63.3	94.8	63.3	96.9	99.2	26.8	72.5	33.5	74.2	74.0	91.6	95.0	76.1	91.2	95.4	81.7	100.0	80.0	93.6	74.5	90.0	93.6	34.5	100.0	92.7
%2Dom Score	62.3	80.4	65.5	31.9	50.2	22.6	67.2	38.0	76.9	74.2	38.6	45.8	62.3	53.8	35.8	20.8	9.2	31.5	56.5	25.0	38.1	63.1	28.9	10.5	40.7
%MFBI Score	50.3	56.7	61.2	47.7	52.8	56.4	69.2	59.2	62.6	63.6	48.8	52.9	55.6	53.5	43.7	41.3	28.6	40.1	32.1	42.2	41.3	43.6	58.4	36.1	39.7
IBI	**29.3**	**44.6**	**42.1**	**38.8**	**42.5**	**25.9**	**48.3**	**28.5**	**47.7**	**44.9**	**33.7**	**37.6**	**38.4**	**39.3**	**33.0**	**23.5**	**19.9**	**26.3**	**31.4**	**23.9**	**33.2**	**39.1**	**26.7**	**23.9**	**32.2**

- Primary biological effects.

* - VSCI Rating: VSCI > 60 (Healthy); VSCI ≤ 60 (Impaired).

The VSCI scores for Turley Creek show a minor impairment in Figure 2-3, while those for Long Meadow Run in Figure 2-4 indicate a consistently stressed biological community. The healthy VSCI scores for Brock Creek, the tributary to Turley Creek, are also shown in Figure 2-3.

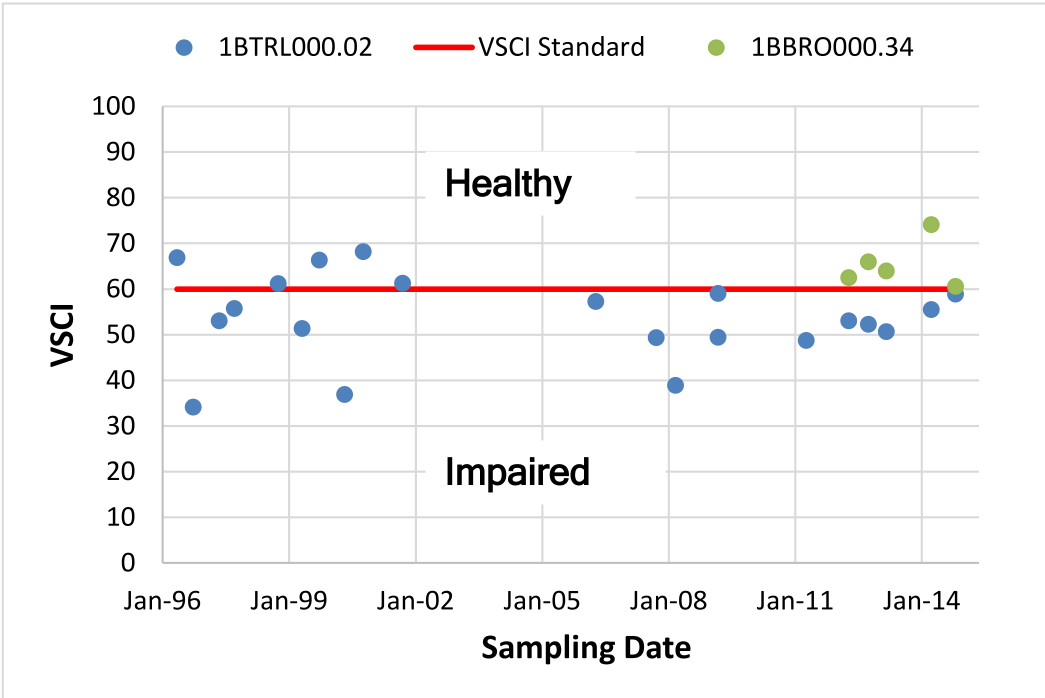

Figure 2-3. VSCI Scores for Turley Creek (TRL)

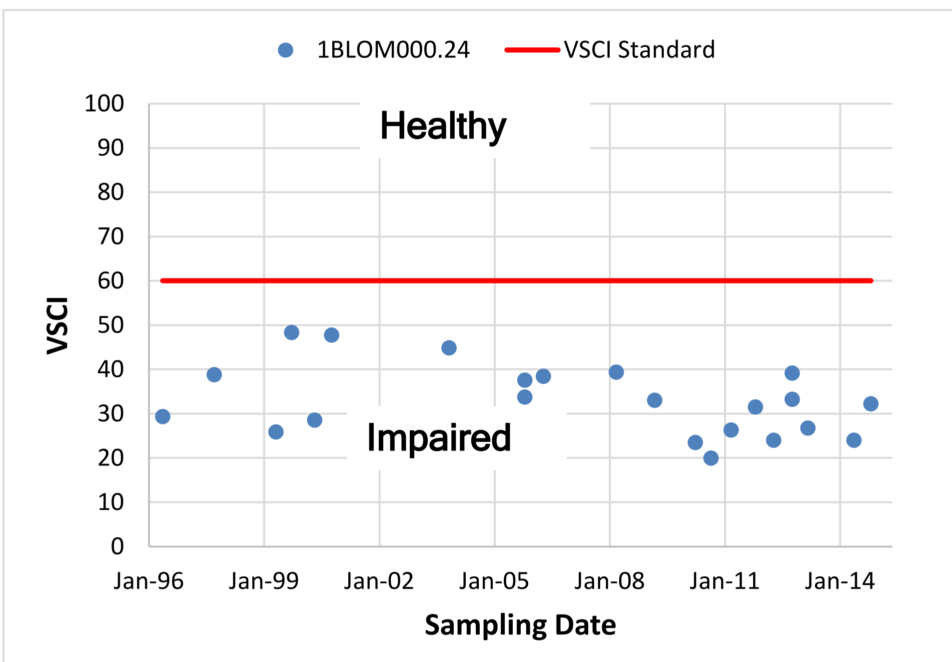

Figure 2-4. VSCI Scores for Long Meadow Run (LOM)

A qualitative analysis of various habitat parameters was conducted in conjunction with each biological sampling event. Habitat data collected as part of the biological monitoring were obtained from DEQ through the EDAS database. Each of the 10 parameters included in the habitat assessment was rated on a scale of 0-20, with a maximum score of 20 indicating the most desirable condition, and a score of 0 indicating the poorest habitat conditions. The best possible overall score for a single evaluation is 200. Many of the “poor” to “marginal” habitat scores shown in these two tables relate fairly closely with the sediment stressor. The habitat assessment data for Turley Creek are shown in Table 2-6 and for Long Meadow Run in Table 2-7.

Table 2-6. Habitat Evaluation Scores for Turley Creek (TRL)

StationID	1BTRL000.02																					
Collection Date	05/29/07	05/30/96	10/16/96	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	10/02/01	05/03/06	10/09/07	03/24/08	03/27/09	10/13/09	10/12/10	04/27/11	11/08/11	04/30/12	10/18/12	03/20/13	Average
Channel Alteration	12	16	10	12	12	11	14	13	16	16	17	15	16	14	16	17	17	15	17	17	16	14.7
Bank Stability	8	6	12	12	9	14	16	14	15	14	11	13	15	10	14	12	14	13	14	12	14	12.5
Vegetative Protection	6	8	10	10	10	7	14	17	6	12	9	14	14	7	14	14	15	16	11	10	13	11.3
Embeddedness	12	8	10	12	15	17	11	11	15	10	11	14		13	17	12	16	11	14	12	17	12.9
Channel Flow Status	20	20	20	16	16	20	18	14	18	15	15	13	16	13	14	12	19	17	17	16	20	16.6
Frequency of riffles (or bends)	16	16	12	14	19	14	18	17	17	19	17	16	17	18	13	17	15	11	16	16	16	15.9
Riparian Vegetative Zone Width	0	0	0	0	0	1	9	5	2	3	4	5	2	3	7	8	10	4	7	9	8	4.1
Sediment Deposition	14	10	8	14	18	16	17	14	19	15	11	14	14	14	12	10	13	12	10	13	12	13.3
Epifaunal Substrate / Available Cover	10	10	10	12	17	17	18	13	16	17	15	18	17	17	16	14	17	17	15	17	16	15.2
Velocity / Depth Regime	16	16	10	12	15	15	18	18	14	16	18	17	16	16	15	14	18	15	16	16	16	15.6
10-metric Total Habitat Score	**114**	**110**	**102**	**114**	**131**	**132**	**153**	**136**	**138**	**137**	**128**	**139**	**127**	**125**	**138**	**130**	**154**	**131**	**137**	**138**	**148**	**131.5**

- Marginal or Poor habitat metric rating.

Table 2-7. Habitat Evaluation Scores for Long Meadow Run (LOM)

StationID	1BLOM000.24																				
Collection Date	06/05/96	10/16/96	05/29/97	10/08/97	10/23/98	05/19/99	10/14/99	05/19/00	10/27/00	11/17/03	11/07/05	05/03/06	03/26/08	03/27/09	04/15/10	09/13/10	03/22/11	11/08/11	04/30/12	03/20/13	Average
Channel Alteration	16	14	10	10	13	10	16	13	13	10	8	10	8	11	12	13	13	9	13	13	11.8
Bank Stability	16	14	14	16	9	12	17	14	14	8	10	8	2	16	10	8	4	16	14	12	11.7
Vegetative Protection	16	14	14	14	16	20	18	18	20	16	18	18	2	12	18	16	16	14	16	13	15.5
Embeddedness	12	12	12	8	16	18	9	16	10	13	16	15	10	11	13	15	15	12	13	14	13.0
Channel Flow Status	20	20	20	20	17	20	18	15	15	19	17	12	15	14	16	14	17	17	17	19	17.1
Frequency of riffles (or bends)	8	8	8	8	11	10	14	10	7	13	5	6	10	11	11	12	8	13	11	13	9.9
Riparian Vegetative Zone Width	6	6	6	4	4	6	10	5	3	4	4	4	4	2	6	8	4	4	8	5	5.2
Sediment Deposition	10	14	10	8	18	15	16	10	14	11	11	1	3	3	4	5	6	3	1	3	8.3
Epifaunal Substrate / Available Cover	12	14	10	8	17	16	17	17	16	17	17	7	9	16	16	5	15	16	17	17	14.0
Velocity / Depth Regime	14	10	10	10	15	14	14	8	10	14	13	12	12	13	14	13	10	14	15	14	12.5
10-metric Total Habitat Score	**130**	**126**	**114**	**106**	**136**	**141**	**149**	**126**	**122**	**125**	**119**	**93**	**75**	**109**	**120**	**109**	**108**	**118**	**125**	**123**	**118.7**

- Marginal or Poor habitat metric rating.

2.7. Water Quality Data

2.7.1. DEQ Ambient Monitoring Data

Ambient water quality sampling has been conducted at one primary station each on Turley Creek (1BTRL000.02) and on Long Meadow Run (1BLOM001.45). An additional sample was taken at a headwater spring in Long Meadow Run (1BLOM007.36) to assess the nutrient concentrations in groundwater. Turley Creek and Long Meadow Run are both designated as Class IV Mountainous Zone Waters (SWCB, 2011).

Turley Creek

Field physical parameters include temperature, pH, dissolved oxygen (DO), and conductivity. Chemical parameters include various forms of nitrogen and phosphorus – nitrite and nitrate N, TKN, total N, ortho-P and total P; total suspended solids; ammonia; hardness; alkalinity; chlorides; sulfates; and bacteria (fecal coliform and *Escherichia coli*).

Monthly plots of ambient monitoring data for Turley Creek are shown in Figures 2-5 through 2-13 for parameters that have been collected from 1991 through 2014, while Figures 2-14 through 2-19 include data from 1991-2001. Some data were analyzed below the minimum detectable limits of analysis, indicated by “MDL”, in some of the figures. Data shown on the horizontal axis as “0” are missing values.

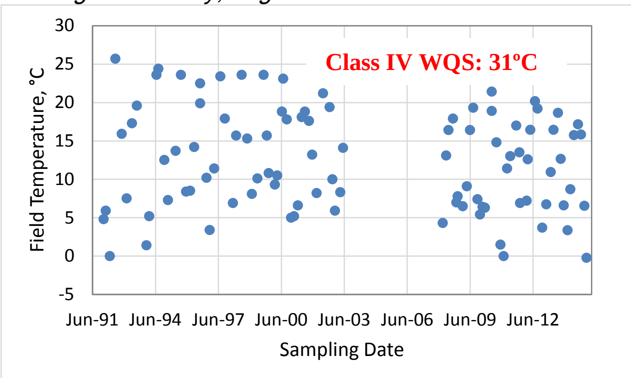

Figure 2-5. Field Temperature

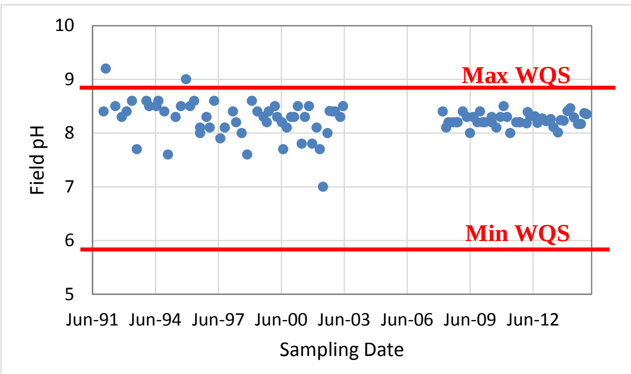

Figure 2-6. Field pH

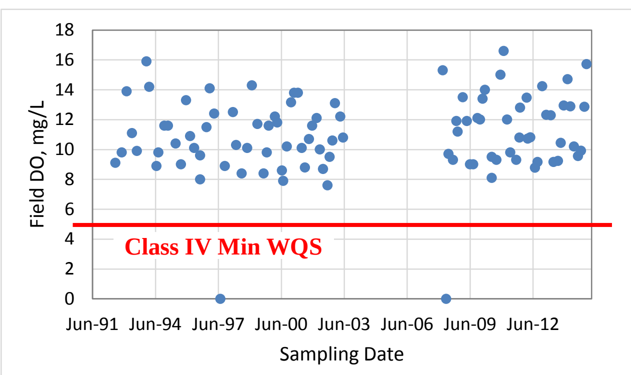

Figure 2-7. Field DO

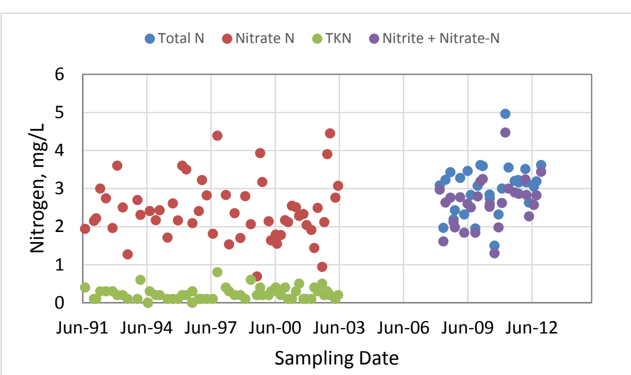

Figure 2-8. Nitrogen

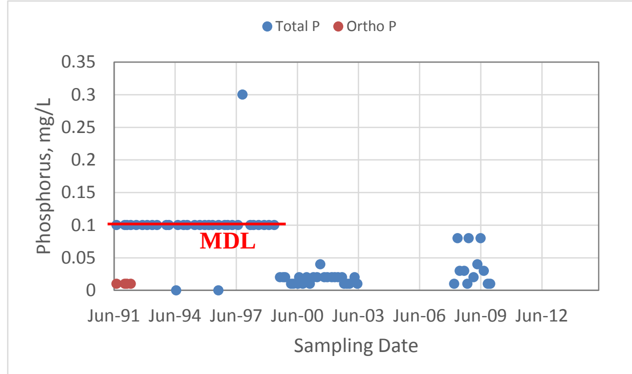

Figure 2-9. Phosphorus

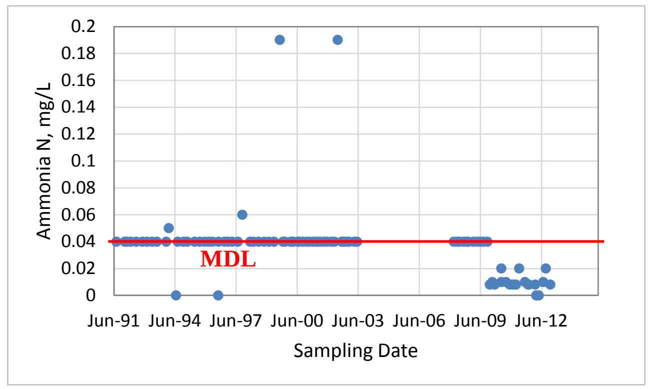

Figure 2-10. Ammonia

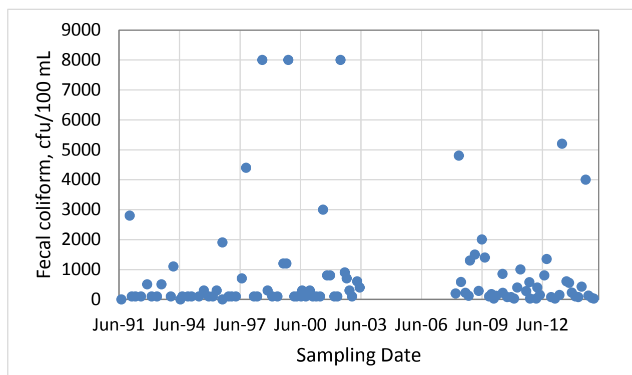

Figure 2-11. Fecal Coliform Bacteria

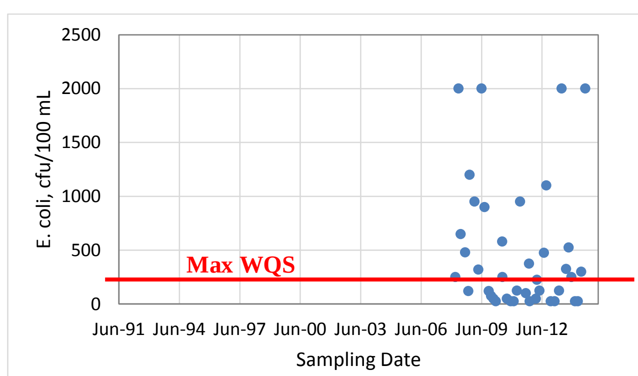

Figure 2-12. Escherichia coli Bacteria

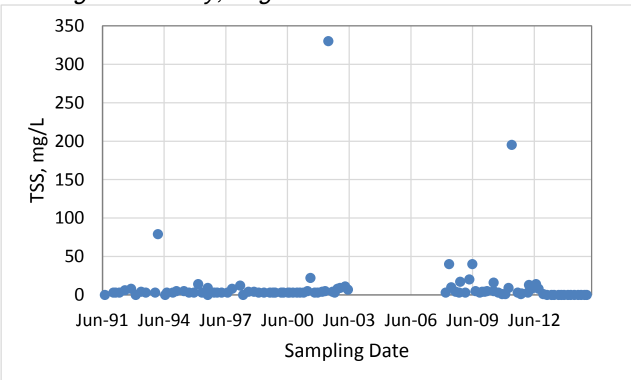

Figure 2-13. Total Suspended Solids (TSS)

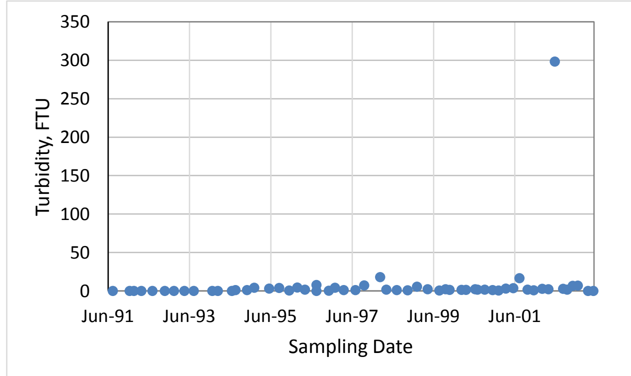

Figure 2-17. Turbidity

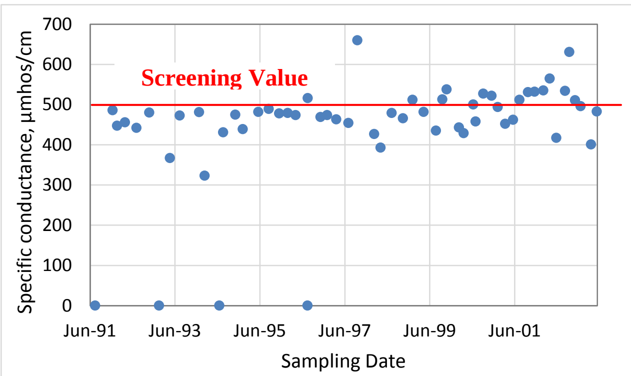

Figure 2-14. Specific Conductivity

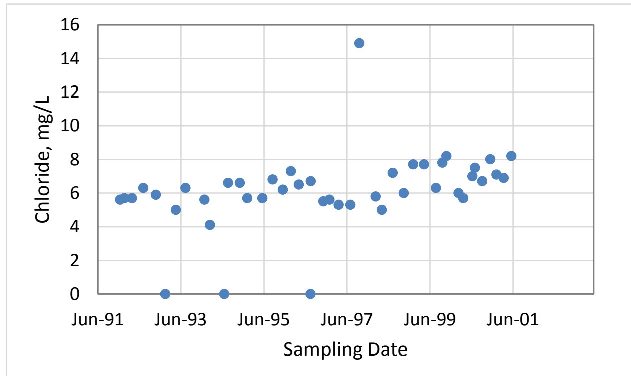

Figure 2-18. Total Chloride

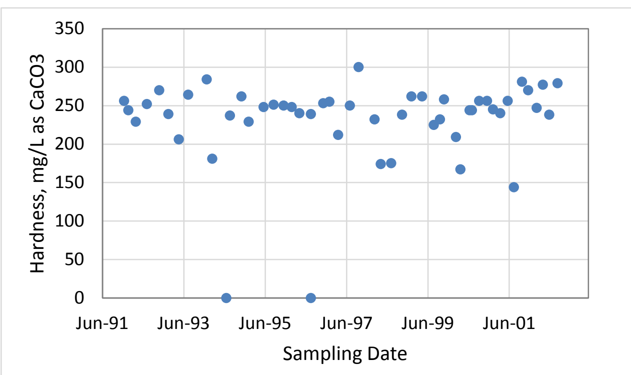

Figure 2-15. Hardness

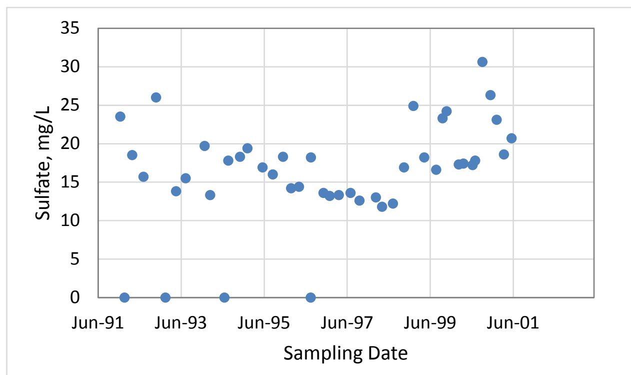

Figure 2-19. Total Sulfate

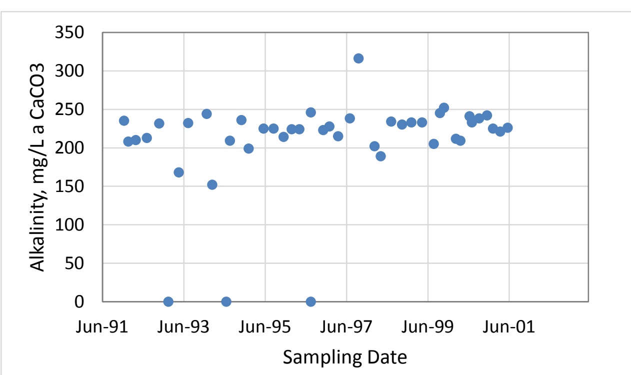

Figure 2-16. Alkalinity

Long Meadow Run

Field physical parameters include temperature, pH, DO, and conductivity. Chemical parameters include non-filterable residue; various forms of nitrogen-nitrite and nitrate N, ammonia, and total N; various forms of phosphorus - ortho-P and total P; turbidity; and bacteria (fecal coliform and Escherichia coli).

Plots of monthly ambient water quality monitoring sample data for the ambient monitoring station in Long Meadow Run (1BLOM001.45) are shown in Figure 2-20 through Figure 2-30. Some figures include data from stations 1BLOM002.24 and 1BLOM007.36, which are headwater springs.

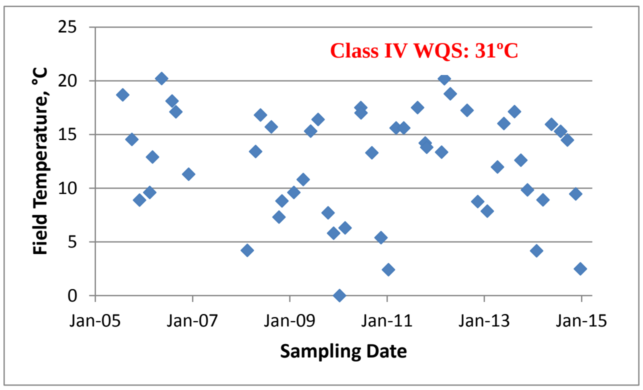

Figure 2-20. Field Temperature

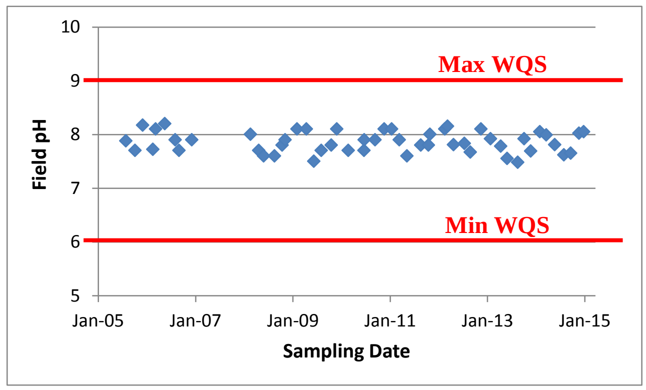

Figure 2-21. Field pH

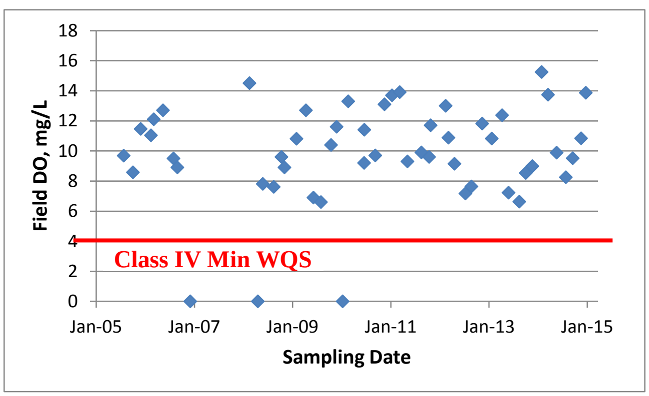

Figure 2-22. Field DO

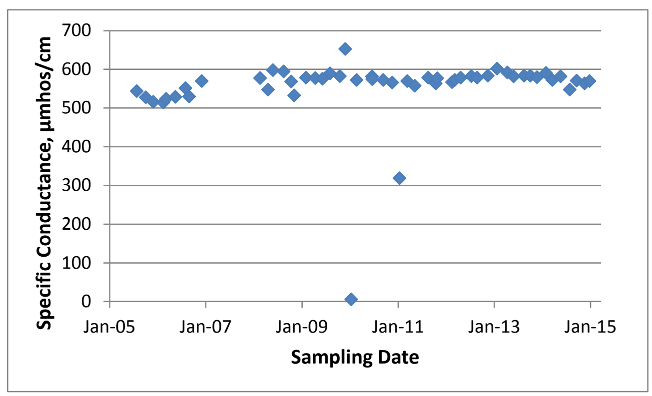

Figure 2-23. Field Conductivity

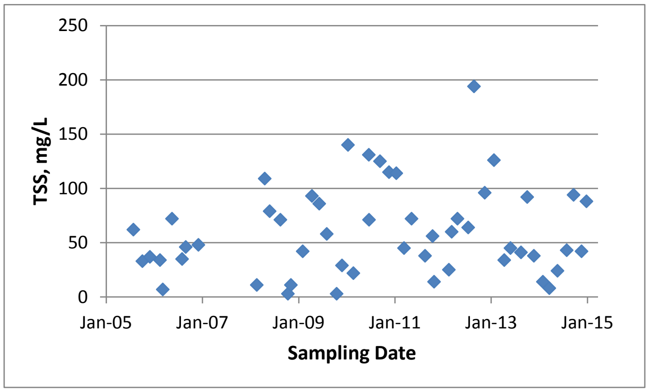

Figure 2-24. Total Suspended Solids (TSS)

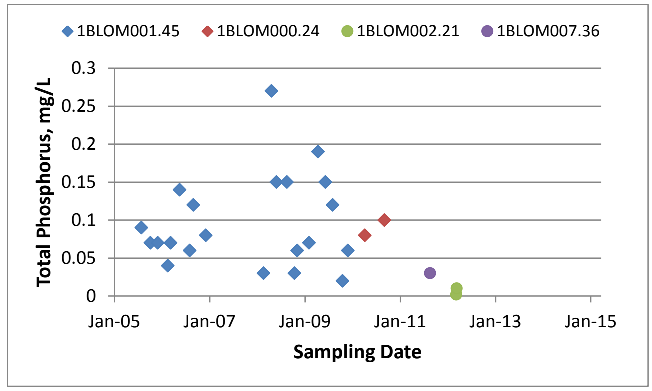

Figure 2-27. Phosphorus

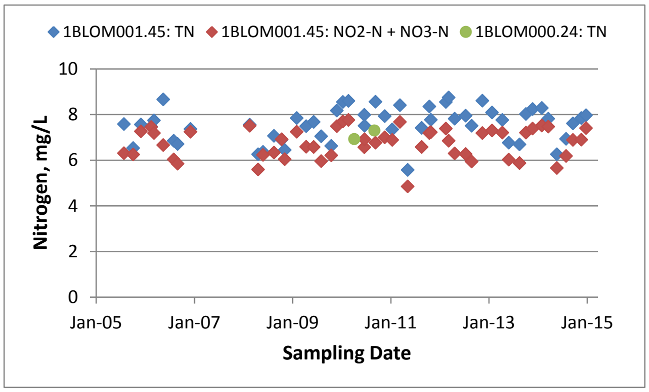

Figure 2-25. Nitrogen

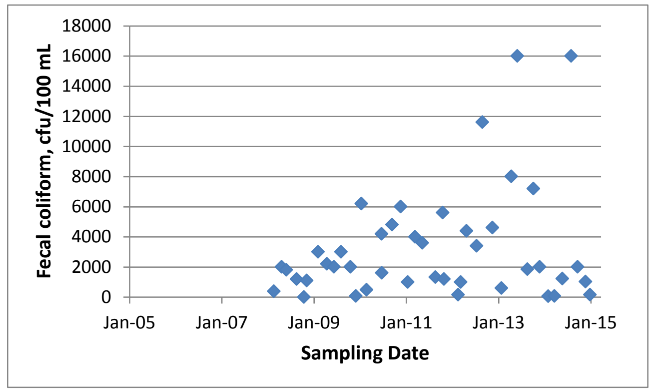

Figure 2-28. Fecal Coliform Bacteria

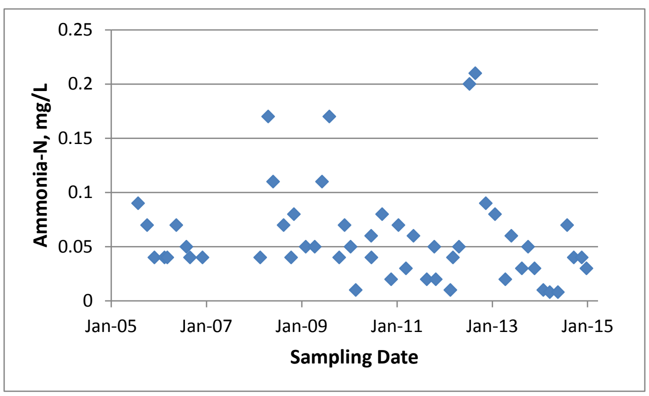

Figure 2-26. Ammonia-N

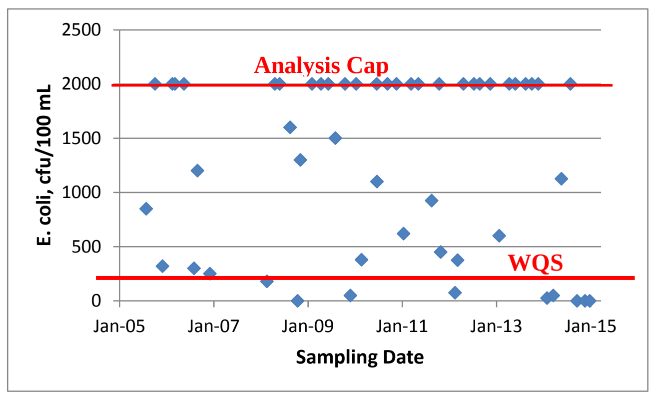

Figure 2-29. *Escherichia coli* Bacteria

2.7.2. DEQ Metals Monitoring Data

Two sediment samples were collected for Turley Creek watershed and analyzed by DEQ for a standard suite of metals, while a third was collected on Long Meadow Run. An additional sediment sample was analyzed as part of a study by Serena Ciparis, Fish and Wildlife Conservation Department at Virginia Tech.

None of the tested substances exceeded any established consensus-based probable effects concentration (PEC), and most of the metals were not detected above their respective minimum detection limit (MDL), as shown in Table 2-8.

Table 2-8. DEQ Channel Bottom Sediment Monitoring for Metals

Parameter Name	Parameter Code	Sample Date				Consensus Based PECs
		Turley Creek* 1BTRL000.02		Long Meadow* 1BLOM000.24	Long Meadow**	
		07/15/92	07/29/96	04/15/10	Mar-07	
ARSENIC SEDIMENT (MG/KG DRY WGT)	1003	5	7	4.76	6.9	33
BERYLIUM, SEDMIMENT (MG/KG DRY WGT)	1013	5	5	0.7		
CD MUD (MG/KG DRY WGT)	1028	5	5	0.46		
CHROMIUM SEDIMENT (MG/KG DRY WGT)	1029	16	16	21.3	19	111
COPPER SEDIMENT (MG/KG DRY WGT)	1043	43	30	10.6	13	149
LEAD SEDIMENT (MG/KG DRY WGT)	1052	18	23	17.7	19	128
MN MUD (MG/KG DRY WGT)	1053		956	334	430	
NICKEL SEDIMENT (MG/KG DRY WGT)	1068	18	17	9.13		48.6
SILVER SEDIMENT (MG/KG DRY WGT)	1078	5	5	0.1		
ZINC SEDIMENT (MG/KG DRY WGT)	1093	56	53	49.1	39	459
ANTIMONY, SEDIMENT (MG/KG DRY WGT)	1098		17	0.2		
AL MUD (MG/KG DRY WGT)	1108		15600	8040	7500	
SELENIUM SEDIMENT (MG/KG DRY WGT)	1148	1	1	0.58		
IRON, SEDIMENT (MG/KG DRY WGT)	1170		24400	13200	12000	
THALLIUM SEDIMENT (MG/KG DRY WGT)	34480	5		0.19		
PCP SEDIMENT (UG/KG DRY WGT)	39061	50	80			676
ALDRIN SEDIMENT (UG/KG DRY WGT)	39333	100	30			
CDANEDRYTECH and METMUDUG/KG	39351	500	40			
DDD MUD (UG/KG)	39363	100	20			28
DDE MUD (UG/KG)	39368	100	20			31.3
DDT MUD (UG/KG)	39373	100	30			62.9
DIELDRIN, SEDIMENT (UG/KG DRY WGT)	39383	100	20			61.8
ENDRIN, SEDIMENT (UG/KG DRY WGT)	39393	100	30			207
TOXAPHEN, SEDIMENT (UG/KG DRY WGT)	39403	1000	160			
HEPTCHLR, SEDIMENT (UG/KG DRY WGT)	39413	100	20			16
PCBS TOTAT, SEDIMENT (UG/KG DRY WGT)	39526	500	30			676
MERCURY, SEDIMENT (MG/KG DRY WGT)	71921	0.3	0.3	0.164		1.06
HPCLEPOX, SEDIMENT (UG/KG DRY WGT)	75045	100	20			
DICOFOL, SEDIMENT (UG/KG DRY WGT)	79799	100	80			
Cobalt, sediment (mg/kg)					6.4	
Barium, sediment (mg/kg)					79	
Calcium, sediment (mg/kg)					42000	
Magnesium, Sediment (mg/kg)					1300	
		(orange)	- At or Below MDL.			
* DEQ periodic sampling.		(green)	- Above MDL, but below method quantification limit.			
** Research study data provided by Serena Ciparis, Virginia Tech.						

2.7.3. DEQ – Other Relevant Monitoring or Reports

Diurnal dissolved oxygen (DO) tests

No exceedences of either the minimum dissolved oxygen standard of 4.0 mg/L, or the daily average standard of 5.0 mg/L for Class IV waters were observed on Turley Creek in August 2008. The diurnal DO test performed during the same time period on Long Meadow failed due to excessive sediment.

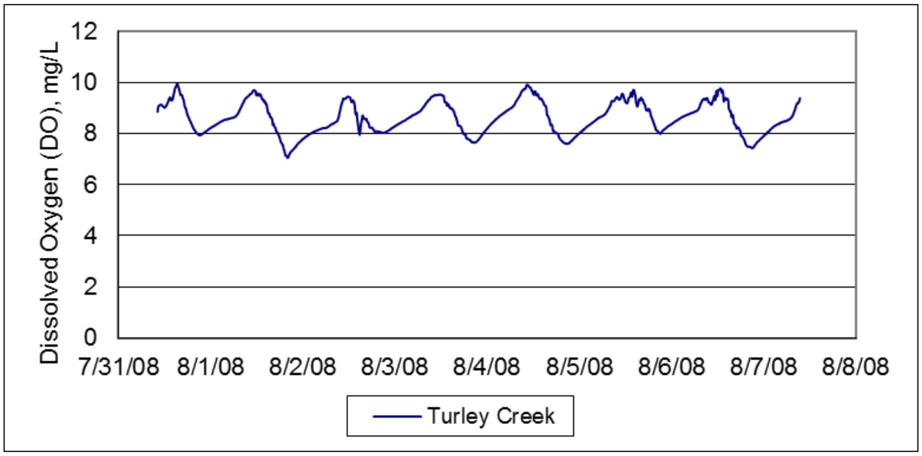

Figure 2-30. 8-Day Diurnal DO Results for Turley Creek

<u>Relative Bed Stability (RBS) Analysis</u>

Turley Creek shows a very low percentage of fine sediment in the stream as shown in Table 2-9. A high percentage of fine sediment in streams would directly contribute to embeddedness, the filling of the interstitial spaces in the channel bottom. The Log Relative Bed Stability (LRBS) score of negative one (-1) indicates that sediments ten times larger than the median are moving at bankfull, with a medium probability of impairment from sediment. DEQ biologists indicated that Long Meadow Run was one of the most unstable streams sampled in Virginia, as shown by the high percentage of fines, the high degree of embeddedness, and the low LRBS score, indicative of highly modified channels.

Table 2-9. RBS Analysis Results

Station	Sample Date	Mean Substrate Size (mm)	LRBS	Mean Embeddedness (channel + margin) (%)	% fines
1BTRL000.02	07/27/10	0.162	-0.857	39.5	13.3
1BLOM000.24	09/13/10	0.095	-2.167	80.4	67.0

2.7.4. DEQ Permitted Point Sources

As of November 3, 2014, there were five general discharge permits for single-family homes in the watersheds, as shown in Table 2-10. Brock Creek is a tributary to Turley Creek.

Table 2-10. Single-Family Home Discharge Permits

Permit No	Classification	Receiving Stream	Watershed
VAG408115	Active	Brock Creek UT	Turley Creek
VAG408174	Active	Long Meadow UT	Long Meadow Run
VAG408227	Active	Long Meadow UT	Long Meadow Run
VAG408352	Active	Turley Creek	Turley Creek
VAG408382	Active	Long Meadow UT	Long Meadow Run

As of November 3, 2014, there were no currently active DEQ VPDES permits for construction stormwater, but there was one industrial stormwater general discharge permit in the Turley Creek watershed, shown in Table 2-11.

Table 2-11. Industrial Stormwater Discharge Permits

Permit No	Facility Name	Classification	Receiving Stream
VAR050808	Neff Lumber Mills Inc	Active	Brock Creek UT

Table 2-12 lists the 23 poultry animal feeding operations (AFOs) active in Long Meadow Run watershed, and 9 poultry AFOs in Turley Creek, as of January 21, 2015.

Table 2-12. AFO Poultry Permits in Turley Creek and Long Meadow Run Watersheds

Permit No	Classification	Land Application	Animal Type	Max. Number at any one time	Avg. number of flocks per year	Watershed Name
VPG260035	Active	No	Chickens, Broiler Breeders	63000	5	Long Meadow Run
VPG260071	Active	Yes	Chickens, Broilers	78000	5.7	Long Meadow Run
VPG260098	Active	No	Chickens, Broilers	25000	6	Long Meadow Run
VPG260126	Active	Yes	Chickens, Broilers	195000	6.5	Long Meadow Run
VPG260151	Active	Yes	Chickens, Broilers	45000	5	Long Meadow Run
VPG260179	Active	Yes	Chickens, Broilers	83000	5	Long Meadow Run
VPG260224	Active	Yes	Turkeys, Grow Out	19000	4	Long Meadow Run
VPG260235	Active	No	Chickens, Broilers	24000	5	Long Meadow Run
VPG260237	Active	No	Chickens, Broilers	58000	5	Long Meadow Run
VPG260261	Active	Yes	Turkeys, Grow Out	50000	3	Long Meadow Run
VPG260303	Active	Yes	Turkeys, Grow Out	22000	3.5	Long Meadow Run
VPG260305	Active	Yes	Chickens, Broilers	75000	7	Long Meadow Run
VPG260319	Active	Yes	Chickens, Broilers	52000	6	Long Meadow Run
VPG260390	Active	Yes	Chickens, Broilers	48000	6.5	Long Meadow Run
VPG260391	Active	Yes	Chickens, Broilers	210000	6.5	Long Meadow Run
VPG260479	Active	No	Chickens, Broilers	50000	5.5	Long Meadow Run
VPG260494	Active	Yes	Chickens, Broilers	57000	6.5	Long Meadow Run
VPG260560	Active	Yes	Chickens, Broiler Breeders	1200000	5	Long Meadow Run
VPG260572	Active	Yes	Chickens, Broiler Breeders	150000	5	Long Meadow Run
VPG260575	Active	No	Turkeys, Grow Out	23000	5.5	Long Meadow Run
VPG260601	Active	Yes	Chickens, Broilers	105000	6	Long Meadow Run
VPG260645	Active	No	Chickens, Broilers	45000	7	Long Meadow Run
VPG260663	Active	Yes	Turkeys, Grow Out	16000	3	Long Meadow Run
VPG260069	Active	Yes	Chickens, Broilers	94000	7	Turley Creek
VPG260157	Active	No	Chickens, Broiler Breeders	24000	1	Turley Creek
VPG260176	Active	No	Chickens, Broilers	49000	5	Turley Creek
VPG260334	Active	No	Chickens, Broilers	72000	7	Turley Creek
VPG260365	Active	Yes	Chickens, Broilers	31000	6	Turley Creek
VPG260520	Active	Yes	Chickens, Broilers	100000	6	Turley Creek
VPG260680	Active	No	Chickens, Broiler Breeders	57000	7	Turley Creek
VPG260683	Active	Yes	Chickens, Broiler Breeders	50000	6	Turley Creek
VPG260757	Active	No	Turkeys, Starter	44000	3.5	Turley Creek

As of November 3, 2014, there is one active mining permit in the Turley Creek watershed, shown in Table 2-13 below. The mining permit carries various requirements for monitoring their operations. Stormwater runoff from the permitted area is directed through an NPDES sediment pond. In-stream monitoring and groundwater monitoring are less permit-specific, so that each monitoring location may serve as compliance for the upstream permitted area.

Table 2-13. DEQ Mining Permit Summary

Permit No	Facility	Classification	No. of Outfalls	Receiving Stream
VAG840133	Rockydale - Broadway Quarry	Active	5	Brock Creek

2.7.5. 305(b)/303(d) Combined Report Monitored Violations

In five of the biennial reports between 1998 and 2010 (VADEQ, 2002, 2004, 2006, 2008, 2010), stations 1BTRL000.02 on Turley Creek and 1BLOM000.24 on Long Meadow Run were listed with biological impairments. Station 1BTRL000.02 also had a bacterial impairment beginning in 2000, while the ambient station (1BLOM001.45) on Long Meadow Run was listed with a bacterial impairment beginning in 2008. All impairments continue through the present. Several minor total phosphorus and chlorophyll a concentrations have been flagged at “threatened” levels, as noted with the other data in Table 2-14 below. Monitored data collected in 2010 and 2011 will be reflected in the 2012 305(b)/303(d) report.

Table 2-14. 305(b)/303(d) Water Quality Standard Violations

Year	Monitoring Station	Type	CONVENTIONAL WATER COLUMN MONITORING DATA #Violations/# Samples/Status									OTHER WATER COLUMN DATA #Violations/# Samples/Status									SEDIMENT #Violations/Status				BENTHIC #Violations/Status				
			Temperature			Dissolved Oxygen			pH			Fecal Coliform			E. Coli			Total Phosphorus			Metals		Organics		Metals		Organics		Bio Mon
1998	1BTRL000.02	A	0	21	S	0	21	S	0	21	S	0	19	S	2	19	T						0	S					
2000	1BTRL000.02	A	0	22	S	0	21	S	0	22	S	1	20	S	4	20	P						0	S					
	1BTRL000.02	B																											MI
	1BLOM000.24	B																											MI
2002	1BTRL000.02	A,B	0	33	S	0	32	S	0	33	S	6	23	IM			N	1	23	S			0	S	0	S			MI
	1BLOM000.24	B	0	9	S	0	9	S	0	9	S																		MI
2004	1BLOM000.24	B	0	10	S	0	10	S	0	10	S																		IV
	1BTRL000.02	A/B	0	39	S	0	39	S	0	39	S	10	27	IM						S			0	S					IV
2006	1BTRL000.02	A/B	0	24	S	0	24	S	0	24	S	7	21	IM				0	21	S			0	S					IV
	1BLOM000.24	B	0	3	S	0	3	S	0	3	S																		IV
2008	1BLOM000.24	B	0	1	W	0	1	W	0	1	W																		IV
	1BLOM001.45	A	0	9	S	0	8	S	0	9	S				9	9	IM	0	9	W									IV
	1BTRL000.02	A,B	0	16	S	0	16	S	0	16	S	7	15	W				0	15	W			0	S					IV
2010	1BLOM000.24	A,B	0	3	S	0	3	S	0	3	S																		IV
	1BLOM001.45	A	0	15	S	0	13	S	0	15	S				13	14	IM						0	S					IV
2012	1BLOM000.24	B	0	5	S	0	5	S	0	5	S				1	1	W						0	S					IM
	1BLOM001.45	A	0	26	S	0	26	S	0	26	S				24	26	IM						0	S					IM
	1BTRL000.02	A,B	0	1028	S	0	8	S	0	24	S				11	18	IM						0	S					

A = DEQ Ambient Monitoring Station
B = DEQ Biological Monitoring Station
FPM = Freshwater Probabilistic Monitoring Station
MP = Citizen Monitoring - Medium Priority for Adverse Conditions
W = Not Assessed
IM = Impaired
S = Supporting

2.7.6. Additional Information

The additional ambient data in Table 2-15 was collected near the Rt. 211 bridge crossing as part of a research study in Long Meadow Run conducted by Serena Ciparis, Fish and Wildlife Conservation Department at Virginia Tech.

Table 2-15. Research Study Data, 2008-09, Serena Ciparis

Date	NO3-N (mg/L)	NH4-N (mg/L)	PO4-P (mg/L)	E2Eq* (ng/L)	TSS (mg/L)	SpCond uS/cm
May-08	5.79	0.22	0.030	3.22	24.4	627.0
Aug-08	7.54	0.05	0.038	0.92	44.7	590.0
Mar-09	6.03	0.04	0.017	1.41	109.3	405.0
May-09	5.85	0.30	0.048	3.89	245.6	622.0
Aug-09	4.84	2.30	0.108	7.49	439.5	646.0

*E2Eq = estrogenic activity, measured with a bioluminescent yeast estrogen screen assay

2.7.7. Household Drinking Water Analyses, Rockingham County

Virginia Cooperative Extension conducted Household Drinking Water clinics in Rockingham County in 1999 and 2009, where homeowners submitted for analysis water samples from their private water supply system. While the samples may not be directly representative of the groundwater quality in the area, they do provide some information on general levels of physical and chemical parameters that may be impacted by groundwater. The VAHWQP uses the EPA primary and secondary standards of the Safe Drinking Water Act, which are enforced for public systems as guidelines for private water supplies. Some interesting trends between 1999 and 2009 are indicated in Table 2-16. Increasing percentages of samples are noted above the recommended level of total dissolved solids (TDS), below the minimum pH drinking water standard (6.5), and above the drinking water nitrate-N standard (10 mg/L) in 2009, compared to 1999. During the same period however, a decreasing percentage of samples indicated the presence of both total coliform and *E. coli* bacteria.

Table 2-16. Household Drinking Water – Water Quality Analyses, 1999 and 2009

Rockingham County		1999 HWQ Drinking Water Test Results					2009 VAHWQP Drinking Water Clinic Results (n=37)		
		Raw Water (n=66)		Tap Water (n=300)					
Test	Standard	Average	Maximum	Average	Maximum	% Exceeding guideline based on EPA standard (Raw/Tap)	Average	Maximum	% Exceeding guideline based on EPA standard
Iron (mg/L)	0.3	0.07	1.80	0.05	1.80	3/5	0.01	0.19	0
Manganese (mg/L)	0.05	0.01	0.28	0.01	0.45	3/4	0.02	0.51	5.4
Hardness (mg/L)	180	249.2	601.4	173.9	601.4	52/79	217.3	478.8	59.5
Sulfate (mg/L)	250	15	99.9	17.8	159.9	0/0	19.5	93.4	0
Chloride (mg/L)	250	42	180	45	353	0/0.003	16	78	0
Fluoride (mg/L)	2.0/4.0	0.54	1.1	0.55	1.46	0/0	0.14	0.41	0
Total Dissolved Solids (mg/L)	500	330	791	356	1303	9/15	403	650	29.7
pH	6.5 to 8.5	7.51	8.46	7.54	8.46	1.0 (below 6.5)	7.33	7.73	5.4 (below 6.5)
Copper (mg/L)	1.0/1.3	0.014	0.517	0.013	0.517	0/0	0.013	0.106	0
Sodium (mg/L)	20	8.1	152.8	45.6	320.7	7/34	47.3	222.6	35.1
Nitrate-N (mg/L)	10	4.6	29.8	4.0	40.4	14/11	4.3	17.9	18.9
Total Coliform Bacteria	ABSENT	--	--	--	--	47/45	--	--	27
E. coli Bacteria	ABSENT	--	--	--	--	17/22	--	--	2.7

Ross et al., 2003 Benham et al., 2010

2.7.8. Mundy Quarry Groundwater Protection Plan (CPI, 2004)

A groundwater protection plan was developed for the C.S. Mundy – Broadway Quarry by the consultant, Continental Placer Inc. (CPI), in December 2004. The following are some findings from that report:

- The average quarry dewatering rate of 0.22-0.30 MGD was rated as minimal to moderate.
- No complaints regarding water quantity or quality issues had been reported since installation of dewatering system in 2003. Two springs on the property continue to flow uninterrupted.
- No other major groundwater users and very few private water supply wells are within a 1,000-foot radius of the Broadway Quarry.
- There have been no significant releases of petroleum products.
- Reclamation plan calls for re-grading the surface and allowing the quarry to fill with water, which should have no impacts on local groundwater.

2.7.9. Hydrologic Modifications, Long Meadow Creek

Much of Long Meadow Run has been channelized in the distant past as is shown by the lack of sinuosity along its length, leading to significant bank erosion, according to DEQ biologists. Also, many in-stream ponds were built in the 1980's as landowners tried to store water, leading to law suits that ruled that the in-stream ponds were permissible, as long as they did not impede flow.

The Virginia Water Protection (VWP) permit program generally exempts small-scale ponds for agricultural use. One of the exclusions of the 9VAC25-210-60 regulation is for the construction and maintenance of farm or stock ponds and farm or stock impoundments that are less than 25 feet in height or create a maximum impoundment capacity smaller than 100 acre-feet. This exclusion however, does not apply to irrigation withdrawals from these ponds or impoundments which do require permitting.

Aerial imagery of the Long Meadow Run watershed reveals a high density of such impoundments in this watershed, which have modified the hydrology in this watershed and could impact both water quality and aquatic life diversity.

Baseflow in Long Meadow Run comes predominantly from two springs – Big Spring, upstream near Lacey Springs Stables, and Holsinger Spring, downstream on Holsinger Road. During periods of low or no rainfall, portions of the main channel (approximately a 4-mile stretch above the downstream spring) become dry and/or intermittent. This watershed is in a karst-dominated region and Long Meadow Run is considered to be a losing stream, with a portion of its normal flow diverted to subterranean flow.

2.7.10. Related TMDLs and/or Implementation Plans

The bacteria impairments in Turley Creek and Long Meadow Run were already addressed by the TMDL developed for the North Fork of the Shenandoah River (Brannan et al., 2006). Any reductions required by the TMDL developed for the benthic impairment will be coordinated with those called for by the bacteria TMDL; primarily these consist of 85% reduction in bacteria (manure) applied to cropland and pasture, and 30% reduction from livestock in streams. An implementation plan has not yet been developed for this watershed.

Chapter 3: BENTHIC STRESSOR ANALYSIS

3.1. Introduction

TMDLs must be developed for a specific pollutant. Since a benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for the impaired watershed in this study. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from DEQ provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Volunteer monitoring data, land use distribution, Virginia Base Mapping Project (VBMP) aerial imagery, Google Earth, and visual assessment of conditions in and along the stream corridor provided additional information to investigate specific potential stressors. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. The candidate benthic stressors considered in the following sections are ammonia, hydrologic modifications, nutrients, organic matter, pH, sediment, TDS/conductivity/sulfates, temperature, and toxics. The information in this section is adapted from the original Stressor Analysis Report for Turley Creek and Long Meadow Run presented to the Local Steering Committee on November 16, 2011.

3.2. Analysis of Stressors for Turley Creek

The suspected sources of the benthic impairment in Turley Creek were listed as "unknown" in the 2012 List of Impaired Waters. The primary DEQ monitoring station for biological monitoring is 1BTRL000.02. In order to further discriminate sources, a stressor analysis was performed on all available data. The stressor may be something that either directly affected the benthic community or indirectly affected its habitat. Virginia SCI ratings suggest that the benthic community has been slightly stressed at different times during the period from 1996 to 2013.

A list of candidate stressors was developed for Turley Creek and evaluated to determine the pollutant(s) responsible for the benthic impairment. A potential stressor checklist was used to evaluate known relationships or conditions that may show associations between potential stressors and changes in the benthic community. Available evidence was then summarized for each potential stressor. Depending on the strength of available evidence, the potential stressors were either “eliminated”, considered as “possible” stressors, or recommended as the “most probable” stressor(s).

3.2.1. Eliminated Stressors

Ammonia

High values of ammonia are toxic to many fish species and may impact the benthic community as well. Even though there were a few instances where the ammonia values recorded at the DEQ ambient monitoring station were slightly elevated, prior to 2010 the majority of recorded values were at or below the minimum detection limit (MDL) of 0.04 mg/L, and since 2010 have averaged about 0.01 mg/L. No fish kills have been reported in this watershed and nothing in the ambient monitoring data indicates ammonia as a stressor, therefore it was eliminated from further consideration as a stressor.

Hydrologic Modifications

Hydrologic modifications can cause shifts in the supply of water, sediment, food supply, habitat, and pollutants from one part of the watershed to another, thereby, causing changes in the types of biological communities that can be supported by the changed environment. There were no signs of hydrologic modifications or major impoundments along Turley Creek. The Mundy Quarry does not appear to be affecting stream flow or groundwater contributions to the stream. Therefore, hydrologic modification was eliminated from further consideration as a stressor.

Metals

Increased metals concentrations lead to low diversity and low total abundance of benthic organisms, with specific reduced abundance of metal-sensitive mayflies and increased abundance of metal-tolerant chironomids (Clements, 1994). Total organism abundance was moderate and no water column or sediment concentrations were reported that exceeded their respective public water supply standards or sediment PECs. Therefore, metals were eliminated from further consideration as a possible stressor.

pH

Benthic macroinvertebrates require a specific pH range of 6.0 to 9.0 to live and grow. Changes in pH may adversely affect the survival of benthic macroinvertebrates. Treated wastewater, mining discharge and urban runoff can potentially alter in-stream levels of pH. No exceedences of the minimum or maximum pH standard were reported at the DEQ monitoring station since 1991. Therefore, pH was eliminated from further consideration as a stressor.

Temperature

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Turley Creek is classified as a Class IV mountain stream with a maximum temperature standard of 31°C. No exceedences of the temperature standard were recorded at the DEQ monitoring station. Therefore, no evidence supported temperature as a stressor, and it was eliminated.

Toxics

Toxic substances by definition are not well tolerated by living organisms. The presence of toxics as a stressor in a watershed may be supported by very low numbers of any type of organisms, low organism diversity, exceedences of freshwater aquatic life criteria or consensus-based Probable Effect Concentrations (PEC) for metals or inorganic compounds, by low percentages of the shredder population, reports of fish kills, or by the presence of available sources. While there are low %shedders, there are abundant organisms present. There have also been no reports of fish kills, and because there are no exceedences of EPA aquatic life criteria or consensus-based PEC's, toxics have been eliminated as a possible stressor.

3.2.2. Possible Stressors

Nutrients

Excessive nutrient inputs can lead to increasing algal growth, eutrophication, and low dissolved oxygen concentrations that may adversely affect the survival of benthic macroinvertebrates. In particular, dissolved oxygen levels may become low during overnight hours due to plant respiration. According to samples collected at the DEQ ambient monitoring station, total nitrogen concentrations are comprised primarily of dissolved N, but concentrations are about half of those reported from groundwater in the household water quality analyses taken in 1999 and 2009. Sources of nitrogen include groundwater, residential wastewater, atmospheric deposition, and agricultural activities. There have been no exceedences of the DEQ's "threatened waters" threshold for total phosphorus since 1998. However, the benthic community is only moderately diversified, with two dominant organisms comprising approximately 58% of each sample. The two dominant organisms - Chironomidae and Hydropsychidae – have been associated with excessive nutrients, and dominate the benthic community in Turley Creek. Therefore, while it is doubtful that nutrients are the dominant stressor, the low riparian vegetation scores also indicate that surface runoff could contribute nutrients, and so, they are considered a possible stressor.

Organic Matter

Excessive organic matter can lead to low in-stream dissolved oxygen concentrations, which may adversely affect the survival and growth of benthic macroinvertebrates. Potential sources of organic matter in Turley Creek include household wastewater discharges, livestock access to streams, runoff from manured agricultural areas, contributions from poultry rendering facilities, and runoff from impervious areas. Organic enrichment is also supported by the types of abundant benthic organisms found in many of the samples – Hydropsychidae and Simuliidae – typical of organic-enriched sites, and the low ratios of scrapers to filterer-collectors, indicative of abundant suspended organic matter used as a food source for the filterer-collectors. Even though there were low levels of BOD and COD (measures of organic enrichment), and no exceedences of the DO standard during diurnal testing, moderate to high MFBI metric scores support organic matter as a possible stressor.

TDS/Conductivity/Sulfates

Total dissolved solids (TDS) are the inorganic salts, organic matter and other dissolved materials in water. Elevated levels of TDS cause osmotic stress and alter the osmo-regulatory functions of organisms (McCulloch et al., 1993). The average TDS and sulfate measurements reported for the DEQ ambient monitoring site on Turley Creek were below the screening values of 500 mg/L and 250 mg/L, respectively. Furthermore, the concentrations in Turley Creek were below the average values for Rockingham County in the household drinking water samples. However, conductivity values exceeded the DEQ reference screening value of 500 μmhos/cm on several occasions between 1995 and 2003. Although the link between TDS/Conductivity/Sulfates and benthic community health is unclear, the high conductivity levels may contribute to the stress being shown by the benthic community, and therefore, was considered a possible stressor.

3.2.3. Most Probable Stressor

The most probable stressor to the benthic community in Turley Creek is considered to be sediment based on the following summary of available evidence.

Sediment

Excessive sedimentation can impair benthic communities through loss of habitat. Excess sediment can fill the pores in gravel and cobble substrate, eliminating macroinvertebrate habitat. Potential sources of sediment include residential runoff, forestry and agricultural runoffs, construction sites, and in-stream disturbances. The soil types within the Turley Creek watershed are highly erodible and therefore susceptible to heavy rainfall events. The headwaters of Turley Creek are intermittent streams and are usually dry, except during the period from January to March. While there were no high TSS concentrations reported at the DEQ ambient monitoring site for Turley Creek, no samples were taken during runoff events when sediment is more likely to be transported. However, sediment is supported as the most probable stressor by the lack of adequate vegetative buffers in the watershed and livestock access to the stream.

3.3. Analysis of Stressors for Long Meadow Run

The suspected sources of the benthic impairment in Long Meadow Run were listed as unknown in the 2012 list of impaired waters. The primary DEQ monitoring stations for ambient and biological monitoring are 1BLOM001.45 and 1BLOM000.24 respectively. A stressor analysis was performed on all available data in order to determine the source(s) of the problem pollutant (stressor). The stressor may be something that either directly affected the benthic community or indirectly affected its habitat. The VSCI ratings suggest that the benthic community has been moderately to severely stressed at different times during the period from 1996 to 2013.

A list of candidate stressors was developed for Long Meadow Run and evaluated to determine the pollutant(s) responsible for the benthic impairment. A potential stressor checklist was used to evaluate known relationships or conditions that may show associations between potential stressors and changes in the benthic community. Available evidence was then summarized for each potential stressor. Depending on the strength of available evidence, the potential stressors were either “eliminated”, considered as “possible” stressors, or recommended as the “most probable” stressor(s). Candidate stressors included ammonia, hydrologic modifications, metals, nutrients, organic matter, pH, sediment, TDS/conductivity/sulfates, temperature, and toxics. The evaluation of each candidate stressor is discussed in the following sections.

3.3.1. Eliminated Stressors

Ammonia

High values of ammonia are toxic to many fish species and may impact the benthic community as well. All of the DEQ ambient monitored ammonia concentrations in Long Meadow Run were less than 0.17 mg/L and nowhere close to the pH- and temperature-variable water quality standard which ranged from 1.00 – 2.77 mg/L on any given day. Ammonia was, therefore, not considered to be a possible stressor.

Metals

Increased metals concentrations lead to low diversity and low total abundance of benthic organisms, with specific reduced abundance of metal-sensitive mayflies and increased abundance of metal-tolerant chironomids (Clements, 1994). The one 2010 channel bottom sediment sample and the 2007 study by Ciparis found no elevated metal concentrations in the sediment. Although total organism abundance was low with low diversity in some of the biological samples, multiple pollutants can cause the same effect. Metals were therefore eliminated as a possible stressor.

pH

Benthic macroinvertebrates require a specific pH range of 6.0 to 9.0 to live and grow. Changes in pH may adversely affect the survival of benthic macroinvertebrates. Treated wastewater, mining discharge and urban runoff can potentially alter in-stream levels of pH. No exceedences of the minimum or maximum pH standard were reported at the DEQ station on the impaired segment. Therefore, pH was eliminated from further consideration as a stressor.

Temperature

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Long Meadow Run is classified as a Class IV mountain stream with a maximum temperature standard of 31°C. No exceedences of the temperature standard were recorded by DEQ ambient monitoring, or by monitoring during collection of the biological samples. Low riparian vegetation habitat metric scores were observed during several biological samplings, but did not correspond with elevated temperature levels. Therefore, no evidence supported temperature as a stressor, and it was eliminated.

3.3.2. Possible Stressors

Hydrologic Modifications

Hydrologic modifications can cause shifts in the supply of water, sediment, food supply, habitat, and the changed environment can support pollutants from one part of the watershed to another, thereby causing changes in the types of biological communities. Anecdotal observations by the DEQ biologists suggest that Long Meadow

Run may have been channelized in the past and appears to be a losing stream in this karst-dominated landscape, with part of the watershed runoff contributing to subterranean flow. While farm ponds and impoundments are exempt from the permitting process as water sources for livestock, the density of impoundments along Long Meadow Run, as revealed through aerial imagery, is fairly high, which could cause changes in seasonal baseflow and the benthic communities that they support. Therefore, hydrologic modification may be a possible stressor.

TDS/Conductivity/Sulfates

Total dissolved solids (TDS) are comprised of the inorganic salts, organic matter and other dissolved materials in water. Elevated levels of TDS cause osmotic stress and alter the osmo-regulatory functions of organisms (McCulloch et al., 1993). While there were no DEQ data for TDS, conductivity measurements for Long Meadow Run watershed were greater than the screening values of 500µmhos/cm and apparently increasing. Rockingham County as a whole, also, has elevated and increasing levels of TDS, as shown in the two sets of household drinking water analyses. Although there were no data available to assess the sulfate levels, and while TDS/Conductivity/Sulfate may not be the most likely cause of the original impairment, it is considered a possible stressor.

Toxics

Toxic substances by definition are not well tolerated by living organisms. The presence of toxics as a stressor in a watershed may be supported by very low numbers of any type of organisms, low organism diversity, exceedences of freshwater aquatic life criteria or consensus-based Probable Effect Concentrations (PEC) for metals or inorganic compounds, by low percentages of the shredder population, reports of fish kills, or by the presence of available sources. While there are low %shedders, there are abundant organisms present. The study by Ciparis revealed detectable levels of estrogens in the water, which although not toxic, may have undesirable effects of aquatic life. Because of the possibility of contributions from the observed livestock processing facility, poultry operations, and stables, toxics are considered a possible stressor

3.3.3. Most Probable Stressor

The three most probable stressors to the benthic community are considered to be nutrients, organic matter and sediment based on the following summary of available evidence.

Nutrients

Excessive nutrient inputs can lead to increasing algal growth, eutrophication, and low dissolved oxygen concentrations that may adversely affect the survival of benthic macroinvertebrates. In particular, dissolved oxygen levels may become low during overnight hours due to plant respiration. Consistently low riparian vegetation scores have been recorded in the habitat metrics for Long Meadow Run, which could promote increased nutrient transport through surface runoff. Average nitrate-N concentrations are significantly above the eutrophication sufficiency level of 0.3mg/L in lakes and are frequently in the 5-8 mg/L range, although only 1 ortho-P measurement from the recent short monitoring period was above the eutrophication sufficiency level of 0.01 mg/L. The monitored high levels of nitrates at the main monitoring site near the outlet are most probably due to groundwater, as concentrations there are similar to concentrations in groundwater drinking samples and in the one sample taken from the major headwater spring. Typically, dissolved nitrogen from overland flows would dissipate at a more rapid pace. The benthic community has a low diversity, with two organisms comprising more than 65% of each sample. Chironomidae and Hydropsychidae – organisms associated with excessive nutrients, dominate the benthic community in Long Meadow Run. Therefore, although phosphorus appears to be limiting, phosphorus loads appear to be minimal, while nitrates are abundant and considered to be a most probable stressor.

Organic Matter

Excessive organic matter can lead to low in-stream dissolved oxygen concentrations which may adversely affect the survival and growth of benthic macroinvertebrates. Potential sources of organic matter in Long Meadow Run include household wastewater discharges, livestock access to streams, runoff from manured agricultural areas, contributions from poultry rendering facilities, and runoff from impervious areas. Organic enrichment is also supported by the types of abundant benthic organisms found in many of the samples – Asellidae, Hydropsychidae and

Simuliidae – typical of organic-enriched sites, and the low ratios of scrapers to filterer-collectors, indicative of abundant suspended organic matter used as a food source for the filterer-collectors. Further research on the Asellidae organism, however, revealed that there are really two subsets of organisms within this family; one which is associated with organic-enriched sites, and the other which is associated with springs (USEPA, 1976). Without lower level differentiation, it is not possible to determine exactly what the unusually high dominance of this family is telling us in this watershed. There are however, consistently high MFBI metric scores, indicative of excessive enrichment. Therefore, organic matter was considered a most probable stressor.

Sediment

Excessive sedimentation can impair benthic communities through loss of habitat. Excess sediment can fill the pores in gravel and cobble substrate, eliminating macroinvertebrate habitat. Potential sources of sediment include residential runoff, forestry and agricultural runoffs, construction sites, and in-stream disturbances. Sediment problems appear to be primarily related to bed-load sedimentation, which is a function of low bank stability, embeddedness, riparian vegetation and sediment deposition scores. Though typically dry, there have been reported instances of flooding at the headwaters, resulting in major erosion upstream. There were also high turbidity measurements reported for the majority of samples taken at the DEQ ambient monitoring station for Long Meadow Run and high TSS concentrations in several 2009 samples taken by Ciparis in her study. Livestock were also observed trampling streambanks and having free access to streams. The diurnal dissolved oxygen testing in this watershed failed due to excess sediment clogging the instruments on the sampling date in 2010. Therefore, despite the relatively high percentage of haptobenthos organisms, which require clean substrates for habitat, the poor habitat metrics related to sediment including embeddedness and bank stability supports sediment as a most probable stressor, as does a DEQ assessment of Long Meadow Run as being one of the most unstable streams in Virginia.

3.4. Summary

The Turley Creek (VAV-B45R_TRL01A00) stream segment is only slightly impaired for its aquatic life use, with recent individual VSCI sample scores ranging between 34 and 69, where a score of 60 or above represents a non-impaired condition (scale: 0 – 100). Turley Creek is impacted primarily by agricultural land uses. Sediment was selected as the most probable stressor based on the poor habitat scores given for the lack of riparian vegetation and livestock access to streams.

The Long Meadow Run (VAV-B45R_LOM01A00) stream segment is moderately to severely impaired for its aquatic life use, with recent individual VSCI sample scores ranging between 25 and 48, where a score of 60 or above represents a non-impaired condition (scale: 0 – 100). Long Meadow Run is impacted by agricultural land uses. Nitrogen, organic matter and sediment were selected as the most probable stressors based on the predominance of organic matter and nutrient-loving organisms, repeated poor scores for riparian vegetation, high nitrate concentrations, and livestock access to streams. The high density of in-stream farm impoundments that affect baseflow in this watershed may also contribute to the impairment within Long Meadow Run.

In addition to the benthic impairments, both Turley Creek and Long Meadow Run also have bacteria impairments which were addressed during a previously developed TMDL (Brannan et al., 2006). Pollutant sources which were subjected to bacteria load reductions in the bacteria TMDL will also affect loads from stressors identified for the biological impairment. In particular, the bacteria TMDL calls for reductions of 85% from bacteria loads on cropland and pasture and 30% reduction from livestock with direct stream access. The bacteria reductions from cropland and pasture, since the loads relate primarily to livestock manure, will also reduce loads of nutrients and organic matter from these sources. Excluding livestock from the streams will further reduce loads of nutrients, organic matter, and sediment.

Since livestock manure is the primary source of organic matter in this watershed, the organic matter stressor should be sufficiently addressed with best management practices (BMPs) called for in the bacteria TMDL and, therefore, organic matter does not require a separate TMDL for the biological impairment. Although some reductions in the nitrogen and sediment biological stressors will accrue from the bacteria TMDL, there are additional sources of sediment in both watersheds and additional sources of nitrogen in Long Meadow Run that merit separate TMDLs for these stressors.

Therefore, a sediment TMDL will be developed to address the biological impairment in Turley Creek, and nitrogen and sediment TMDLs will be developed to address the biological impairment in Long Meadow Run.

Chapter 4: SETTING REFERENCE TMDL LOADS

Since there are no in-stream water quality standards for either nitrogen or sediment in Virginia, an alternate method was needed for establishing a reference endpoint that would represent the "non-impaired" condition.

In the past, a reference watershed approach has been used based on a single reference watershed that has similar characteristics as the TMDL watershed, except that it has a healthy benthic community. In the reference watershed approach, the modeled pollutant load in the reference watershed is set as the TMDL (threshold) level in the impaired watershed. One problem with this reference watershed approach can be finding a suitable reference watershed, especially for minimally-impaired and urban watersheds. A second problem is in identifying the threshold pollutant load that is sufficient, without being excessive, for attainment of biological integrity in the impaired watershed, since the load from the reference watershed is typically overly conservative.

4.1. The AllForX Approach

For the Turley Creek and Long Meadow Run impairments, the procedure used to set TMDL endpoint loads is a modification of the methodology used to address sediment impairments in Maryland's non-tidal watersheds (MDE, 2006, 2009), hereafter referred to as the "all-forest load multiplier" (AllForX) approach. AllForX is the ratio of the simulated pollutant load for existing conditions to the pollutant load from an all-forest condition for the same watershed. The AllForX approach was applied locally for Turley Creek and Long Meadow Run, using a selection of watersheds with monitoring stations that have healthy biological scores. A regression was developed between the average Virginia Stream Condition Index (VSCI) biological index scores at impaired and selected comparison monitoring stations and the corresponding AllForX ratio from their contributing watersheds. The full AllForX methodology is detailed in Appendix F.

4.1.1. Selection of Local Comparison Watersheds

The AllForX comparison watersheds were selected using these criteria:

- nearby watersheds (within 30 miles)
- Average VSCI > 60 and a minimum VSCI > 55

- Minimum of 3 VSCI samples
- The most recent VSCI sample taken since January 2005
- 2nd - 4th order streams
- No upstream-downstream comparison watersheds

4.1.2. Sediment TMDL Endpoints

Eleven potential comparison watersheds were identified for application of the AllForX approach in both the Turley Creek and Long Meadow Run watersheds for establishing sediment TMDL endpoints. After performing load calculations, the number of comparison watersheds for use with Turley Creek was reduced to nine, as AllForX values for two of the watersheds were larger than those of the Turley Creek watershed, and therefore, not appropriate for setting pollutant reduction targets for Turley Creek. Table 4-1 summarizes the various characteristics in support of the selection criteria for each of the potential comparison watersheds, while Figure 4-1 illustrates the location of the comparison monitoring sites and watersheds to the Turley Creek and Long Meadow Run monitoring sites and watersheds. The highlighted watersheds in Table 4-1 are the comparison watersheds that were excluded in the comparison with Turley Creek.

Table 4-1. Summary of Comparison Watershed Characteristics

Station ID	Stream Name	Sub-ecoregion Code	Ecoregion	VAHU6	No. of Samples	Minimum VSCI	Average VSCI	First Sampling Date	Last Sampling Date
1BBRO000.34	Brock Creek	67a	Northern Limestone/Dolomite Valleys	PS55	3	62.9	64.3	04/30/12	03/20/13
1BBVR003.60	Beaver Creek	67a	Northern Limestone/Dolomite Valleys	PS14	7	60.2	70.3	05/08/97	10/25/12
1BCDR045.30	Cedar Creek	67c	Northern Sandstone Ridges	PS71	5	62.3	74.0	03/25/11	04/11/13
1BCUB000.40	Cub Run	67a	Northern Limestone/Dolomite Valleys	PS38	10	61.5	75.1	05/06/97	03/22/11
1BLAR001.77	Laurel Run	67c	Northern Sandstone Ridges	PS65	6	62.8	74.0	03/25/11	05/02/13
1BLEW009.19	Lewis Creek	67a	Northern Limestone/Dolomite Valleys	PS06	8	56.5	63.3	06/02/04	09/20/12
1BLSC003.52	Little Stony Creek	67c	Northern Sandstone Ridges	PS66	3	67.2	70.3	04/23/12	05/30/13
1BMFT002.46	Moffett Creek	67a	Northern Limestone/Dolomite Valleys	PS05	7	66.5	76.1	03/20/08	05/18/12
1BMIL007.79	Mill Creek	67a	Northern Limestone/Dolomite Valleys	PS63	5	57.9	65.8	05/06/05	10/25/12
1BNAK000.30	Naked Creek	67a	Northern Limestone/Dolomite Valleys	PS36	3	64.9	67.1	10/28/08	03/25/10
1BNTH046.75	North River	67d	Northern Dissected Ridges and Knobs	PS12	7	64.7	72.7	11/03/94	04/16/12

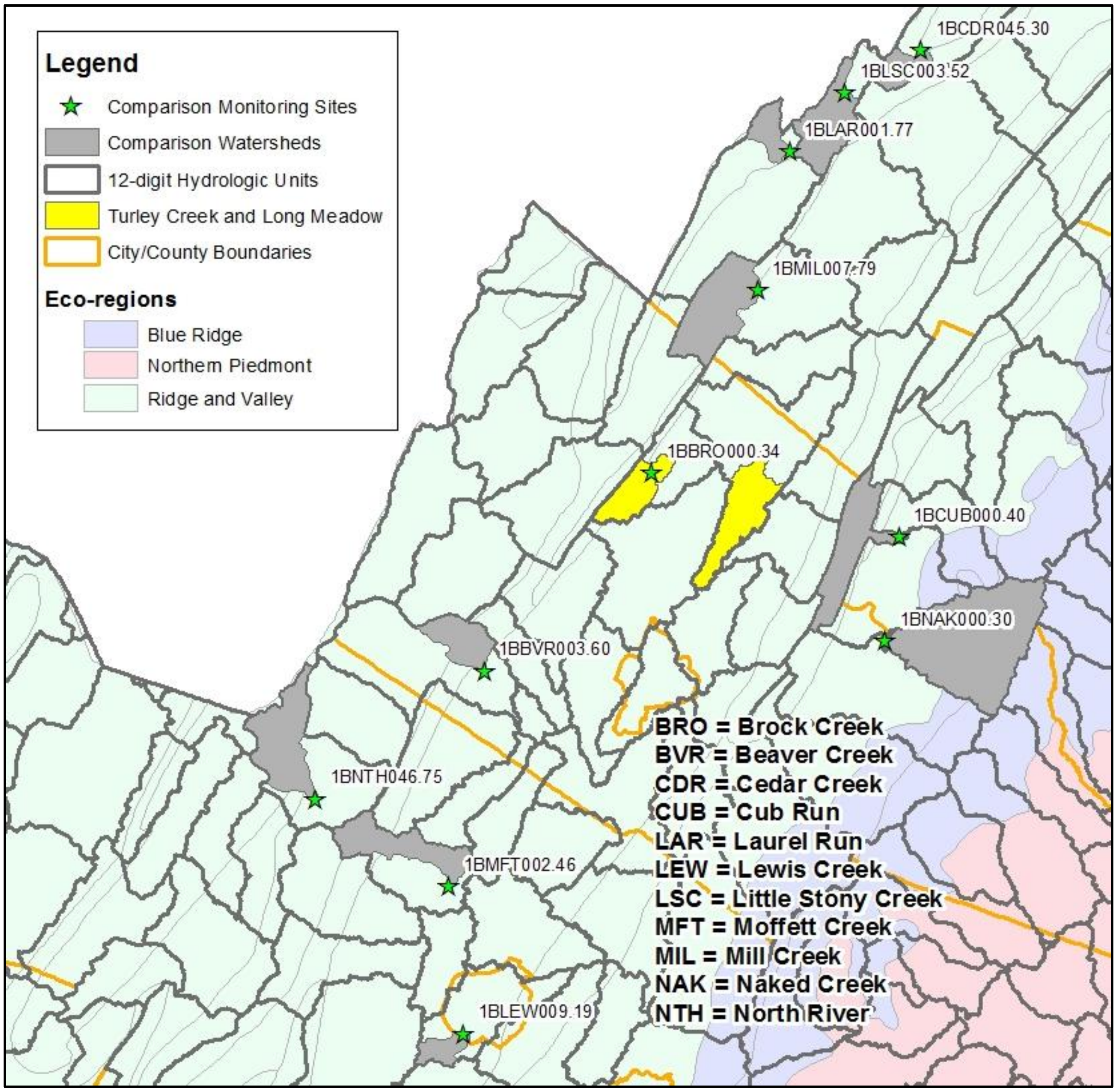

Figure 4-1. Location of Turley Creek, Long Meadow Run and Comparison Watersheds

The resulting regressions used for obtaining the AllForX threshold values and confidence intervals for setting the sediment TMDL endpoints for Turley Creek and Long Meadow Run are shown in Figure 4-2 and Figure 4-3, respectively.

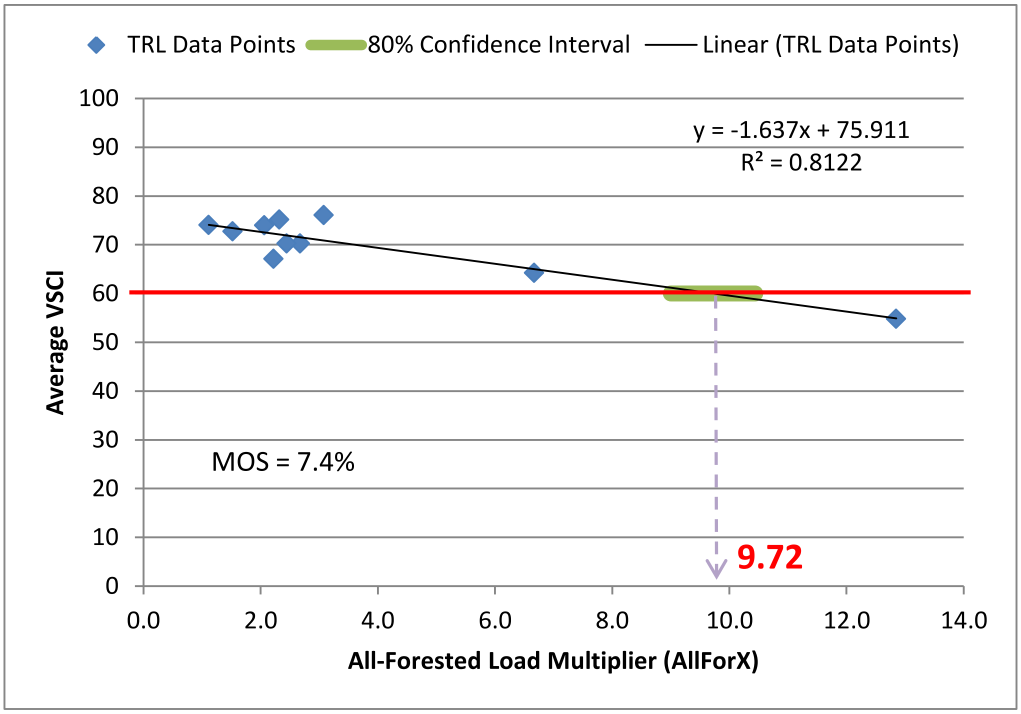

Figure 4-2. Sediment AllForX Regression, Turley Creek

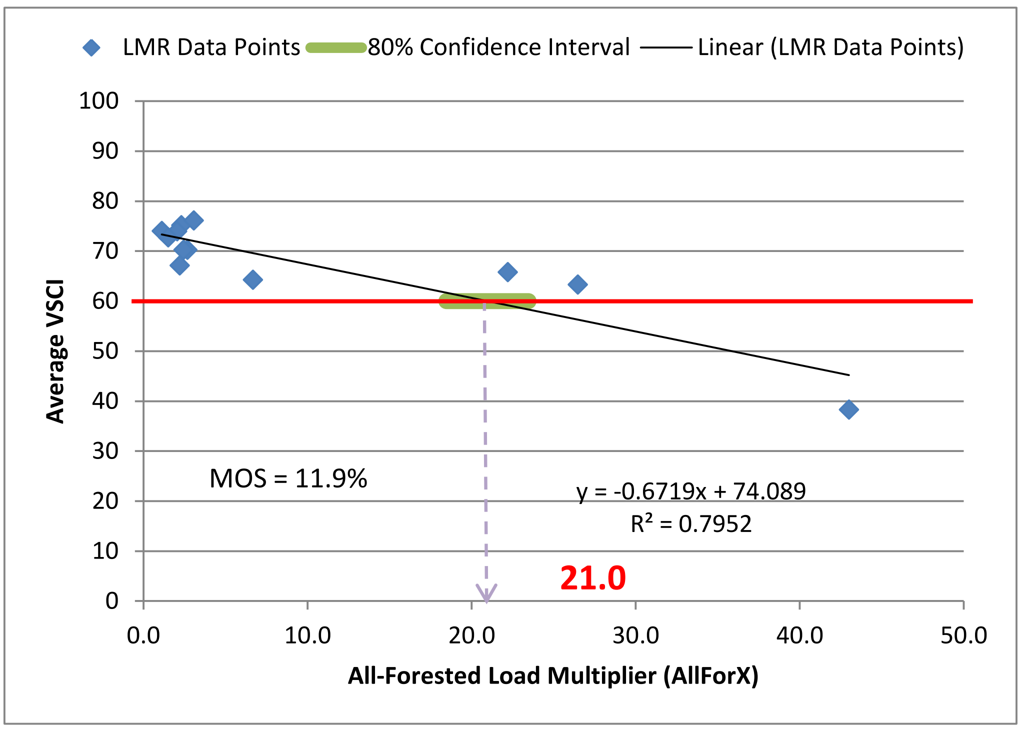

Figure 4-3. Sediment AllForX Regression, Long Meadow Run

4.1.3. Nitrogen TMDL Endpoint

For Long Meadow Run, the same comparison watersheds were used for calculation of the nitrogen AllForX ratios as for sediment. The resulting regression used for obtaining the AllForX threshold value and confidence interval for setting the nitrogen TMDL endpoint for Long Meadow Run is shown in Figure 4-4.

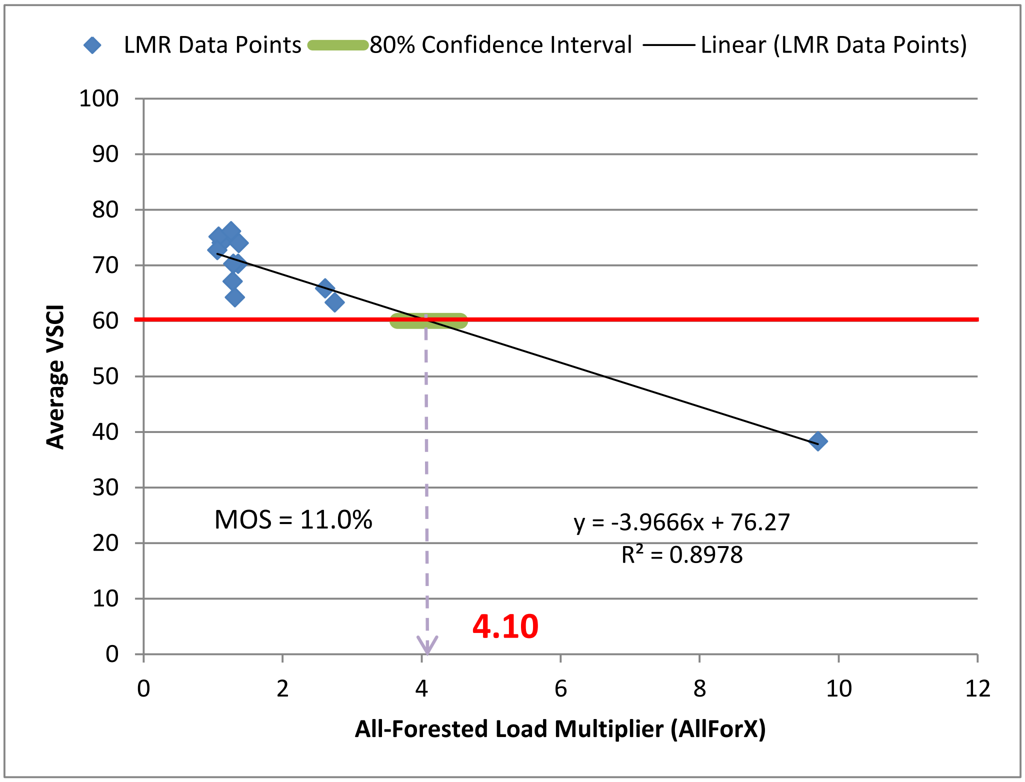

Figure 4-4. Nitrogen AllForX Regression, Long Meadow Run

4.1.4. Reasonable Assurance

Although these TMDLs are developed for sediment (as well as nitrogen for Long Meadow Run), attainment of a healthy benthic community will ultimately be based on biological monitoring of the benthic macro-invertebrate community, in accordance with established DEQ protocols. If a future review should find that the reductions called for in these TMDLs based on current modeling are found to be insufficiently protective of local water quality, then revision(s) will be made as necessary to provide reasonable assurance that water quality goals will be achieved.

Chapter 5: MODELING PROCESS FOR DEVELOPMENT OF THE TMDLS

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship is developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutant(s) and that cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In the development of the sediment TMDL for the Turley Creek watershed and the nitrogen and sediment TMDLs for the Long Meadow Run watershed, the relationship between pollutant sources and pollutant loading to the stream was defined by land uses and areas assessed from the NASS 2009 cropland data layer, together with non-land based loads and simulated output from a computer watershed loading model. The modeling process, input data requirements, and TMDL load calculation procedures are discussed in this chapter.

5.1. Model Selection

The model selected for development of the sediment TMDL in the Turley Creek watershed and the nitrogen and sediment TMDLs for the Long Meadow Run watershed was the Generalized Watershed Loading Functions (GWLF2010) model, originally developed by Haith et al. (1992), with modifications by Evans et al. (2001), Yagow et al. (2002), and Yagow and Hession (2007). The model was run in metric units and converted to English units for this report.

The loading functions upon which the GWLF model is based are compromises between the empiricism of export coefficients and the complexity of process-based simulation models. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and non-point sources of pollution. The model considers flow inputs from both surface runoff and groundwater. The hydrology in the model is simulated with a daily water balance procedure that considers different types of storages within the system. The GWLF model was originally developed for use in ungaged watersheds. Although one study recommends hydrologic calibration to improve runoff simulation estimates (Dai et al., 2000), absence of observable flow in the many comparison watersheds in this study led to the original decision to simulate loads in a non-calibrated mode.

However, during simulation of the nitrogen loads on Long Meadow Run, it was apparent that the baseflow/total flow ratio was critical in calculating reasonable nitrogen loads. Therefore, a limited baseflow and nitrogen calibration were conducted in order to simulate Long Meadow Run with an average flow rate around 3 cfs (based on limited flow measurements at USGS station 01632367 on Long Meadow Run at Route 793 ranging from 0.66 – 4.04 cfs on 11 dates from 2008 – 2012), and an average N concentration around 7.5 mg/L (based on the average of 52 samples at 1BLOM001.45, ranging from 5.57 – 8.74 mg/L). The calibration produced an actual average flow of 3.35 cfs, an actual average N baseflow concentration of 8.0 mg/L, and a combined in-stream concentration of 7.0 mg/L). Additional calibration details are provided in Appendix H.

GWLF uses three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains input data primarily related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types. The Penn State Visual Basic™ version of GWLF with modifications for use with ArcView was the starting point for additional modifications (Evans et al., 2001). The following modifications related to sediment were made to the Penn State version of the GWLF model, as incorporated in their ArcView interface for the model, AvGWLF v. 3.2:

- Urban sediment buildup was added as a variable input.
- Urban sediment washoff from impervious areas was added to total sediment load.
- Formulas for calculating monthly sediment yield by land use were corrected.
- Mean channel depth was added as a variable to the streambank erosion calculation.

The GWLF2006 version of GWLF (Yagow and Hession, 2007) was used in previous TMDL studies. The GWLF2006 version included a correction to the flow accumulation calculation in the channel erosion routine that was implemented in December 2005 (VADEQ, 2005). This version also included modifications from Schneiderman et al. (2002) to include an unsaturated zone leakage coefficient, to remove the annual boundary for transported sediment distribution, and to add in missing bounds for the calculation of erosivity using Richardson equations which were intended to have minimum and maximum bounds on daily calculations. These minimum and maximum bounds were not included in GWLF 2.0, and have been added to keep calculations within physically expected bounds. Delivered loads were also recoded as a function of transported, instead of detached, sediment. The current GWLF2010 version restored the original annual boundary for transported sediment distribution to correct a minor calculation error.

Erosion is generated using a modification of the Universal Soil Loss Equation. Sediment supply uses a delivery ratio together with the erosion estimates, and sediment transport takes into consideration the transport capacity of the runoff. Stream bank and channel erosion was calculated using an algorithm by Evans et al. (2003) as incorporated in the AVGWLF version (Evans et al., 2001) of the GWLF model and corrected for a flow accumulation coding error (VADEQ, 2005).

Model input data were created for each of the Turley Creek and Long Meadow Run sub-watersheds along with each of the eleven comparison watersheds, for simulation of sediment and nitrogen loads. Model development for all watersheds was performed by assessing the sources of sediment and nitrogen in each watershed, evaluating the necessary parameters for modeling loads, and finally applying the model and procedures for calculating loads.

Since the headwater sub-watersheds in both Turley Creek and Long Meadow Run are nested within a downstream watershed, the land segments were simulated uniquely, so that the land areas and associated loads do not overlap. Total loads to downstream segments were summed from both upstream segments, with adjustments to sub-watershed loads to account for differential delivery factors (representative of in-stream attenuation and a function of cumulative upstream watershed area). Also, since channel erosion is calculated as a power function of cumulative upstream area, channel erosion for individual sub-watersheds that received flow from upstream sub-watersheds was a subtractive process. Channel erosion for a downstream sub-watershed was calculated as the channel erosion from the cumulative watershed at its outlet minus the channel erosion calculated for upstream sub-watersheds.

The Turley Creek and Long Meadow Run impaired segments and the modeled sub-watersheds are shown in Figure 5-1.

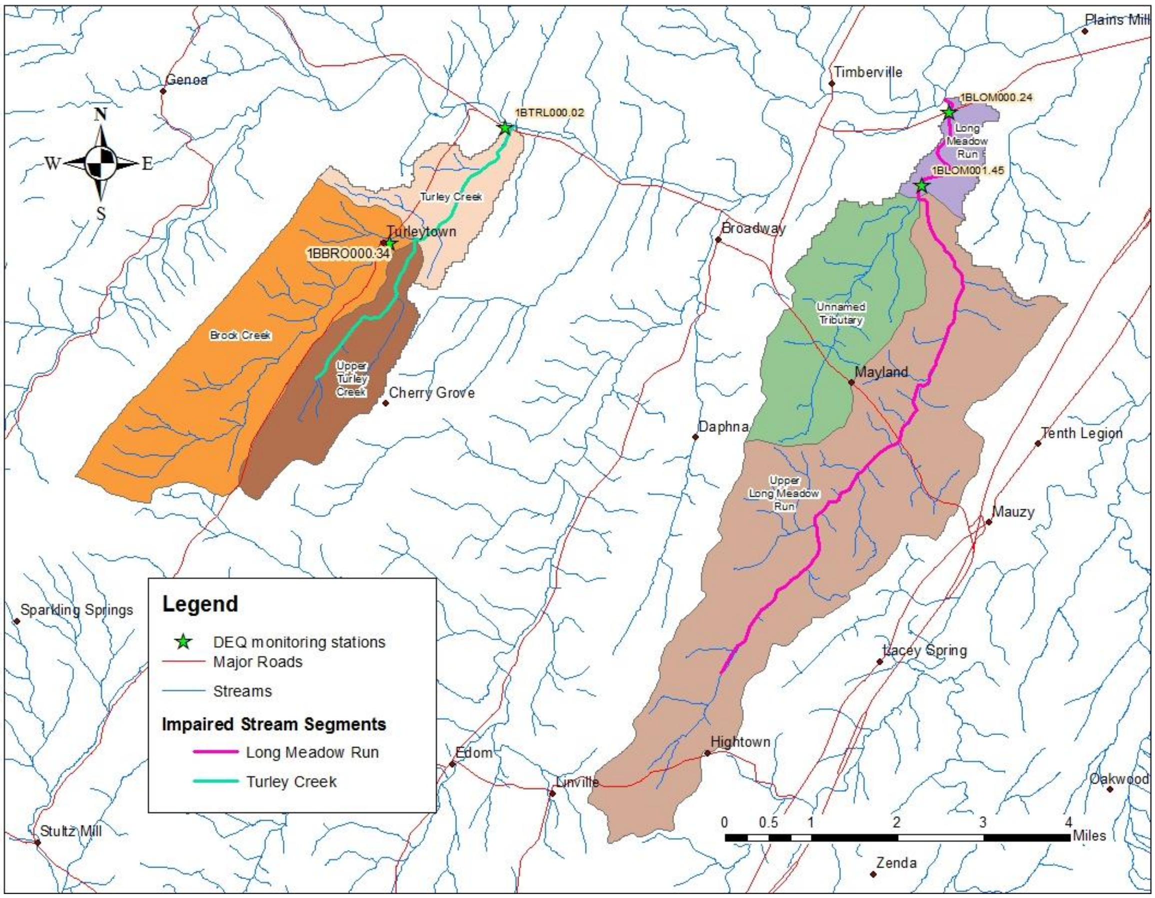

Figure 5-1. Turley Creek and Long Meadow Run Modeled Sub-watersheds

5.2. Input Data Requirements

5.2.1. Climate Data

The climate data for all of the Turley Creek and Long Meadow Run and comparison watersheds were extracted from the Climate Forecast System Reanalysis

(CFSR) program interface hosted at Virginia Tech (cfsr.bse.vt.edu). This system extracts and interpolates precipitation and temperature data for the period 1979-2010 from all available national weather sources using the 4 to 8 nearest NCDC, NOAA, NEXRAD, and other weather data to create continuous, seamless daily precipitation and temperature records for any given location. Locations were defined by centroid coordinates that were generated through GIS analysis for each impaired and comparison watershed in order to generate a unique precipitation and temperature input time-series for each watershed. The period of record used for sediment and nitrogen TMDL modeling was a nineteen-year period from January 1992 through December 2010, with the preceding nine months of data used to initialize storage parameters.

5.2.2. Existing Land Use

For setting the TMDL endpoints using the AllForX method, modeled land uses for Turley Creek, Long Meadow Run, and the comparison watersheds were all derived from the USDA National Agricultural Statistics Service (NASS) digital cropland data layer for 2009.

For simulation of existing loads in the impaired watersheds, the land use distribution was derived from the USDA National Agricultural Statistics Service (NASS) cropland data layer for 2009. The NASS categories were the same as used in setting the TMDL endpoints using the AllForX method, except that the following refinements were made to the distribution. The NASS categories were consolidated into general land use categories of Row Crop, Hay, Pasture, Forest, and various “developed urban” categories, as shown in Table 5-1, and then redistributed based on the rationale given below.

Table 5-1. NASS Land Use Group Distributions

Simulated Watershed	Watershed Code	Row Crop	Pasture/Hay	Forest	Barren	Low intensity developed	Medium intensity developed	High intensity developed	Water	Total
		Area in acres								
Impaired Watersheds										
Long Meadow Run	LOM1x	1,022.2	6,553.5	1,667.3	6.4	621.4	15.8	0.8	1.6	9,889.1
Turley Creek	TRL1x	226.3	2,023.3	3,478.6	271.7	3.9	1.5	8.2	12.7	6,026.1
Comparison Watersheds										
Brock Creek	TRL3	21.3	697.7	2,664.3	0.3	4.6	3,531.8	1.2	7.0	6,928.2
Beaver Creek	BVR	45.5	205.1	4,992.0	3.9	5,396.3	0.0	0.0	0.0	10,642.8
Cedar Run	CDR	0.0	5.1	3,096.1	0.0	0.0	0.0	3,101.3	0.0	6,202.6
Cub Run	CUB	30.6	281.7	9,106.6	0.0	0.0	9,722.7	0.0	0.0	19,141.6
Laurel Run	LAR	0.0	27.6	3,036.6	0.0	3,177.1	0.0	0.0	0.0	6,241.3
Lewis Creek	LEW	111.5	1,538.6	526.8	2,488.0	0.0	0.0	0.0	6.2	4,671.2
Little Stony Creek	LSC	6.0	265.9	7,621.4	0.0	0.0	0.0	0.0	0.8	7,894.1
Moffett Creek	MFT	21.3	890.2	10,289.2	0.0	0.0	0.0	0.0	3.1	11,203.8
Mill Run	MIL	364.1	2,997.0	4,740.6	0.0	0.0	0.0	0.0	0.8	8,102.5
Naked Creek	NAK	249.4	2,607.0	23,591.1	0.0	0.0	0.0	0.0	0.0	26,447.5
North River	NTH	0.0	24.9	10,598.6	0.0	0.0	0.0	0.0	10.8	10,634.3

The Row Crop category was subdivided into hi-till and low-till categories based on Conservation Tillage Information Center (CTIC) data as incorporated in the 2006 Virginia Statewide NPS Watershed Assessment (Yagow and Hession, 2007). The combined Pasture/Hay acreages were distributed as 85% pasture and 15% hay based on based on an assessment by local conservation personnel. From the Pasture category, the “riparian”, and “animal feeding operation” land uses were calculated as 0.0271 and 0.0075 times the total Pasture area, respectively, as estimated from proportions within the Chesapeake Bay Watershed Model (CBWM) land-river segment PS2_5560_5100. The remaining Pasture area was sub-divided into 10% “good”, 65% “fair”, and 25% “poor” pasture land uses, based on an assessment by local conservation personnel. A “harvested forest” land use was created as 1% of the Forest category, similar to procedures used in the CBWM (USEPA, 2010a). The “barren” category area was re-assigned as 1% of all the developed land use categories (barren, LDI, MDI, and HDI) for each watershed, and subtracted from either the Urban Open Space (Pervious_LDI) or Low Intensity Developed (LDI) land use. The “developed” categories were sub-divided into pervious and impervious portions, with “urban open space” assigned to the pervious portion of the “low intensity developed” land use. Impervious percentages were calculated as 20%, 50%, and 80% for the low intensity, medium intensity and high intensity developed areas, respectively. The general category land uses and their simulated derivations are summarized in Table 5-2, while detailed land use distributions are included in Appendix B.

Table 5-2. Modeled Land Use Categories

NASS Groups	NASS Land Uses	% Impervious	Modeled Land Use Categories
Row Crop	Corn, Sorghum, Soybeans, Barley, Winter Wheat, Rye, Dbl. Crop WinWht/Corn, Dbl. Crop Barley/Corn, Dbl. Crop Barley/Soybeans	0	Hi-till cropland
			Lo-till cropland
Hay	Alfalfa	0	Hay
Pasture	Other Pasture/Hays, Pasture/Grass	0	Good pasture
			Fair pasture
			Poor pasture
			Riparian pasture
			Animal feeding operation
Forest	Deciduous, evergreen, and mixed forest	0	Forest
			Harvested Forest
Barren	Barren	0	Barren
Pervious_LDI	Urban open space	0	Pervious LDI
LDI	Developed, low intensity (LDI)	0	Pervious LDI
		20	Impervious LDI
MDI	Developed, medium intensity (LDI)	0	Pervious MDI
		50	Impervious MDI
HDI	Developed, high intensity (LDI)	0	Pervious HDI
		80	Impervious HDI

Each land use within a sub-watershed formed a hydrologic response unit (HRU). Model parameters were then calculated for each HRU using GIS analysis to reflect the variability in topographic and soil characteristics across each watershed. A description of model parameters follows in section 5.4.

5.3. Future Land Use

The Rockingham County 2010 Comprehensive Plan shows all of Turley Creek watershed and the majority of Long Meadow Run watershed within the "Agricultural Reserve" area of the County. A small fringe portion of Long Meadow Run is zoned as "Residential" on the outskirts of Broadway north of Holsinger Road and west of

American Legion Drive, which has not yet been fully developed. In addition, the County's Conceptual Land Use Plan for 2020 and 2050 includes another possible residential growth area on the fringe of the watershed north of Holsinger Road. Future residential development, however, would amount to less than 0.1% of the Long Meadow Run watershed. As no major changes are envisioned for the watersheds, future land use in the watershed will be represented only as the existing land use plus land use changes related to the current level of BMP implementation and with inclusion of a Future Growth WLA equal to 1% of the TMDL.

5.4. GWLF Parameter Evaluation

All parameters were evaluated in a consistent manner for all watersheds in order to ensure their comparability. The hydrology, sediment and nitrogen parameters are described in detail in Appendix D. All GWLF parameter values were evaluated from a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures (Evans et al., 2001), procedures developed during the 2006 statewide NPS pollution assessment (Yagow and Hession, 2007), calibration (Appendix H), and best professional judgment.

Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file. Nutrient parameters are all included in GWLF's nutrient input file. Descriptions of each of the hydrologic, sediment, and nutrient parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses. The GWLF parameter values used for each of the Long Meadow Run, Turley Creek, and comparison watersheds are detailed in Appendix E.

5.5. Supplemental Post-Model Processing

After modeling was performed on individual and cumulative sub-watersheds, model output was post-processed in a Microsoft Excel™ spreadsheet to summarize the modeling results and to account for existing levels of BMPs already implemented within each watershed.

The extent and effect of existing agricultural BMPs in the TMDL modeling were based on implementation data through the end of 2014, provided by the Shenandoah Valley SWCD and Virginia NRCS for the sixth-order watersheds that encompass Turley Creek watershed (PS55) and Long Meadow Run watershed (PS57).

The extent and effect of existing agricultural BMPs (through 2007) in the AllForX modeling (for both TMDL and comparison watersheds) were based on passthru fractions developed by Virginia DCR to represent fractions of landuse-specific loads reduced by BMPs for sixth-order watersheds that encompasses each impaired or comparison watershed, as used in the 2014 Virginia Nonpoint Source Assessment and reported to the Chesapeake Bay Watershed Model (CBWM). Modeled sediment and nitrogen loads within each land use category were then multiplied by their respective passthru fractions to simulate the reduced loads resulting from existing BMPs.

The extent and effect of existing agricultural BMPs for TMDL modeling were assessed from SWCD and NRCS implementation tracking data to assess BMPs active through 2009 (considered as the baseline for the TMDL study) and through 2014, along with CBWM BMP efficiencies. More detailed information on BMP processing is included in Appendix G.

Sediment BMPs are required on harvested forest lands and on disturbed lands subject to Erosion and Sediment (E&S) regulations. A sediment efficiency of 60% was used for BMPs on harvested forest land, while sediment reductions from disturbed land was assumed to be subject to E&S permits with a sediment efficiency of 40%; a nitrogen sediment efficiency of 50% was used for BMPs on harvested forest land, while sediment reductions from disturbed land was assumed to be subject to E&S permits with a nitrogen efficiency of 25% (USEPA, 2010b). Existing BMPs were assumed to be achieving only half of those potential efficiencies.

5.6. Representation of Sediment and Nitrogen Sources

Sediment is generated in the Turley Creek and Long Meadow Run watersheds through the processes of surface runoff, in-channel disturbances, and streambank and channel erosion, as well as from natural background contributions and permitted sources. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses.

Nitrogen in the watersheds is in both the particulate and dissolved forms. Particulate nitrogen is attached to sediment and moves in association with its transport and is preferentially attached to the finer particles. Dissolved nitrogen results from surface runoff and leaching of excess fertilizer and manure, septic system discharge, stormwater runoff from impervious areas, and permitted point source discharges.

Permitted dischargers in Turley Creek and Long Meadow Run watersheds currently include only stormwater discharges. Stormwater discharges include construction permits regulated through Virginia's Erosion and Sediment Control Program and urban stormwater runoff from MS4, municipal, industrial and general permits.

5.6.1. Surface Runoff

During runoff events, sediment and nitrogen loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil and attached nutrients are detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices. During periods without rainfall, dirt, dust, fine sediment, and attached nutrients build up on impervious areas through dry deposition, which is then subject to washoff during rainfall events. Pervious area sediment loads were modeled using a modified USLE erosion detachment algorithm, monthly transport capacity calculations, and a sediment delivery ratio in the GWLF model to calculate loads at the watershed outlet. Pervious area nutrient loads were simulated as loading functions of both runoff and sediment. Impervious area sediment and nutrient loads were modeled in the GWLF model using an exponential buildup-washoff algorithm. Septic system dissolved nutrient loads were simulated as a function of population and system type.

5.6.2. Groundwater Contributions to Baseflow

Nitrogen loading from groundwater was simulated as a loading function of groundwater flow.

5.6.3. Channel and Streambank Erosion

Channel and streambank erosion was modeled within the GWLF model using a modification of the routine included in the AVGWLF version of the GWLF model (Evans et al., 2001). This routine calculates average annual streambank erosion as a function of percent developed land, average area-weighted curve number (CN) and K-factors, watershed animal density, average slope, streamflow volume, mean channel depth, and total stream length in the watershed. Livestock population, which figures into animal density, was estimated based on a stocking density of 0.1667 animal units per acre of available pasture (AU/acre). Nitrogen loads associated with channel and streambank erosion were simulated as loading functions of sediment.

5.6.4. Urban Stormwater

Permitted sources of urban/residential storm water runoff include individual and general industrial storm water permits and Virginia Storm Water Management Program (VSMP) permits, which include permits for Municipal Separate Storm Sewer Systems (MS4s).

<u>Industrial Stormwater</u>

As of November 3, 2014, there were only one active Industrial Storm Water General Permit (ISWGP) and one Non-metallic Mineral Mining (NMMM) General Permit, both in the Brock Creek sub-watershed of the Turley Creek watershed. The Broadway Quarry has been previously referred to by its former owner, C.S. Mundy. The existing sediment load for each facility was simulated as part of the urban pervious and impervious land use categories. Permitted sediment WLA loads for each facility were calculated as the permitted area of the facility times the average annual runoff (simulated for low intensity developed areas) times the permitted average sediment concentration (100 mg/L TSS for the ISWGP permit; 30 mg/L TSS monthly average for the NMMM permit), as shown in Table 5-3. There were no industrial stormwater permits in Long Meadow Run.

Table 5-3. Industrial Stormwater General Permit (ISWGP) WLA Loads

VPDES Permit Number	Facility Name	Source Type	Receiving Stream	Area (acres)	% Impervious	Average Annual Runoff* (in/yr)	TSS WLA (tons/yr)
VAG840133	Rockydale - Broadway Quarry	NMMM	Brock Creek	75	5.33	7.04	1.79
VAR050808	Neff Lumber Mills Inc	ISWGP	Brock Creek	17.66	40	25.32	5.07

* Simulated as an area-weighted average of urban pervious and impervious areas at each site.
TSS WLA (tons/yr) = X acres * Y mg/L * Z in/yr * 102,801.6 L/acre-inch * 1 lb/453,600 mg * 1 ton/2000 lbs = X * Y * Z * 0.000113317
NMMM = non-metallic mineral mining; ISWGP = industrial stormwater general permit.

<u>Construction Stormwater</u>

Although currently there are no active construction stormwater permits in either Turley Creek or Long Meadow Run, loads from this intermittent activity are expected to occur periodically. To account for periodic construction stormwater loads, “barren” land use was estimated as 1% of all developed land uses, except the pervious_LDI category (which often times includes urban recreational areas). Existing loads simulated from the “barren” land use were used to represent the load from construction stormwater in each watershed. Aggregated construction WLA loads will be calculated during the allocation scenario by applying the overall average percent reduction needed to achieve the TMDL in the watershed to the “barren” existing loads.

Although recent construction occurred in the watershed related to installation of the Columbia natural gas pipeline, as a public utility, they are exempt from the permitting process.

<u>Municipal Separate Storm Sewer Systems (MS4)</u>

There are no MS4 permits in either Turley Creek or Long Meadow Run Creek watershed.

5.6.5. Poultry Farm Permits

Animal feeding operations (AFOs) are permitted agricultural facilities in Virginia. In Long Meadow Run and Turley Creek, the only livestock with AFO permits are poultry. As of January 2015, there were 23 poultry animal feeding operations (AFOs) active in Long Meadow Run watershed and 9 poultry AFOs in Turley Creek. Since these are non-discharge permits, neither existing loads nor WLAs are calculated for these facilities. Manure produced by the operations is represented by the manure operations inputs and nutrient loading factors. From the Pasture category, the “riparian”, and “animal feeding operation" land uses were calculated as 0.00374 and 0.00044 times the total Pasture area, respectively, as estimated from proportions within the Chesapeake Bay Watershed Model (CBWM) land-river segment PS5_5200_4380.

5.6.6. Other Permitted Sources (VPDES and General Permits)

As of November 3, 2014, there were no active individual non-stormwater VPDES discharge permits.

There are two types of onsite wastewater treatment systems (OWTS): discharging systems (permitted and regulated jointly by DEQ and VDH) and non-discharging systems (certified and regulated by VDH). Permitted OWTS systems operate under a general VPDES discharge permit (12VAC5-640). There were seven (7) general discharge permits for single-family homes (SFH) in the two watersheds: five in Long Meadow Run watershed, and two in the Turley Creek watershed. Additionally, sediment and nitrogen loads from non-discharging septic systems were evaluated from 2010 census data as the non-sewered population in the watershed (881 people). Septic system nutrient loads were explicitly calculated with the GWLF model, with no distinction between discharging and non-discharging systems, and effluent loads at the end of the drainfield represented as 4 kg N/person/yr with minor additional plant uptake during the growing season. For the allocation scenario, WLA loads for the discharging systems were calculated in aggregate as the number of SFH permits times 0.001 MGD (1,000 gallons/day) times the 9VAC25-110-80 permitted TSS concentration of 30 mg/L for sediment and the 12VAC5-613-10-90 nitrogen requirement in the Chesapeake Bay watershed not to exceed 20 mg/L, times appropriate units conversion factors, as shown in Table 5-4. Alternative onsite wastewater treatment systems and their associated reductions were represented as BMPs. Load allocations for the non-discharging systems were calculated in the allocation scenarios.

Table 5-4. Discharging OWTS SFH General Permit WLAs

No. of Permits	Watershed	VAG Numbers	TSS WLA (tons/yr)	TN WLA (lbs/yr)
5	Long Meadow R	408174, 408227, 408382	0.21	304.6
2	Turley Creek	408115, 408352	0.08	NA

TSS WLA = 0.001 MGD * 30 mg/L * 1.3817 = 0.041 t/system-yr
TN WLA = 0.001 MGD * 20 mg/L * 3046.1 = 60.92 t/system-yr

5.7. Accounting for Critical Conditions and Seasonal Variations

5.7.1. Selection of Representative Modeling Period

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed. A long period of weather inputs was selected to represent long-term variability in the watershed. The period of record used for sediment and nitrogen TMDL modeling was a period from April 1991 through March 2011, with the initial nine months of data used to initialize storage parameters. The 19-year period from January 1992 through December 2010 was used to calculate average annual sediment loads in all watersheds.

5.7.2. Critical Conditions

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area, and included "dry", "normal" and "wet" years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

5.7.3. Seasonal Variability

The GWLF model used for this analysis considered seasonal variation through a number of mechanisms. Daily time steps were used for weather data and water balance calculations. The model also used monthly-variable parameter inputs for evapo-transpiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

5.8. Existing Sediment Loads

Existing pollutant loads were initially simulated for all individual land uses and septic systems with the GWLF model, as discussed previously, accounting for installed BMPs active at the end of 2007. The resulting sediment loads in Turley Creek and Long

Meadow Run are given in Table 5-5, and nitrogen loads in Long Meadow Run in Table 5-6, together with aggregate unit-area loads (tons/ac-yr for sediment and lbs/ac-yr for nitrogen) for each land use.

Table 5-5. Existing Sediment Loads in Turley Creek and Long Meadow Run Watersheds

2007 BMP Scenario TMDL Watersheds

Land Use/Source Categories	LOM1 Lower Long Meadow Run	LOM2 Upper Long Meadow Run	LOM3 Unnamed Tributary	LOM1x Long Meadow Run Total	TRL1 Lower Turley Creek	TRL2 Upper Turley Creek	TRL3 Brock Creek	TRL1x Turley Creek Total	LOM1x Average Unit-Area Sediment Loads	TRL1x
	Sediment Load (tons/yr)								(tons/ac-yr)	
HiTill Rowcrop (hit)	20.0	309.2	115.6	**444.8**	46.5	45.4	7.9	**99.8**	1.60	1.62
LoTill Rowcrop (lot)	12.6	195.3	71.8	**279.7**	29.5	28.4	5.0	**62.9**	0.38	0.38
Pasture (pas_g)	1.6	24.1	7.1	**32.8**	2.9	3.7	4.4	**11.0**	0.06	0.07
Pasture (pas_f)	49.8	816.0	260.0	**1,125.8**	102.8	137.2	146.9	**386.9**	0.32	0.36
Pasture (pas_p)	41.5	728.1	231.7	**1,001.3**	91.0	122.7	122.8	**336.4**	0.74	0.81
Riparian pasture (trp)	15.5	272.7	86.8	**375.1**	34.0	46.0	45.9	**125.9**	2.48	2.70
AFO (afo)	2.1	37.4	12.0	**51.5**	4.7	6.3	6.2	**17.2**	1.24	1.34
Hay (hay)	9.3	155.0	49.4	**213.7**	19.5	26.1	27.9	**73.5**	0.22	0.24
Forest (for)	0.1	12.4	3.3	**15.9**	6.8	5.6	56.3	**68.6**	0.01	0.02
Harvested forest (hvf)	0.0	1.2	0.3	**1.5**	0.6	0.5	4.9	**6.1**	0.09	0.18
Transitional (barren)	0.9	20.5	7.3	**28.7**	2.3	4.1	4.1	**10.4**	4.46	3.62
Pervious LDI (pur_LDI)	1.4	30.7	11.0	**43.1**	2.9	6.0	11.5	**20.4**	0.07	0.08
Pervious MDI (pur_MDI)	0.0	0.3	0.1	**0.4**	0.0	0.0	0.1	**0.1**	0.06	0.05
Pervious HDI (pur_HDI)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**	0.03	0.04
Impervious LDI (imp_LDI)	0.2	3.5	1.0	**4.6**	0.3	0.2	1.2	**1.7**	0.16	0.21
Impervious MDI (imp_MDI)	0.2	2.5	0.5	**3.1**	0.0	0.1	0.6	**0.8**	0.39	0.40
Impervious HDI (imp_HDI)	0.0	0.3	0.0	**0.3**	0.0	0.0	0.5	**0.5**	0.41	0.41
Channel Erosion	1.4	0.1	0.3	**1.8**	1.8	0.3	0.7	**2.8**		
Point Sources	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**		
Total Existing Sediment Load	156.6	2,609.3	858.2	**3,624.1**	345.6	432.7	446.8	**1,225.1**		

Table 5-6. Existing Nitrogen Loads in Long Meadow Run Watershed

2007 BMP Scenario

Land Use/Source Categories	LOM1	LOM2	LOM3	**LOM1x**	**LOM1x**
	Lower Long Meadow Run	**Upper Long Meadow Run**	**Unnamed Tributary**	**Long Meadow Run Total**	**Average Unit-Area Nitrogen**
	Nitrogen Load (lbs/yr)				**(lbs/ac-yr)**
HiTill Rowcrop (hit)	58.6	627.6	239.9	**926.0**	3.32
LoTill Rowcrop (lot)	181.2	1,858.1	683.1	**2,722.4**	3.66
Pasture (pas_g)	28.7	280.4	75.7	**384.8**	0.72
Pasture (pas_f)	468.2	5,231.9	1,468.6	**7,168.7**	2.05
Pasture (pas_p)	314.0	3,878.4	1,111.2	**5,303.6**	3.94
Riparian pasture (trp)	64.5	859.3	279.9	**1,203.6**	7.97
AFO (afo)	73.9	1,106.3	315.2	**1,495.5**	35.93
Hay (hay)	61.2	701.3	199.8	**962.4**	0.98
Forest (for)	0.2	32.7	7.1	**40.0**	0.02
Harvested forest (hvf)	0.0	2.7	0.6	**3.3**	0.20
Transitional (barren)	0.9	16.1	6.3	**23.3**	3.62
Pervious LDI (pur_LDI)	18.4	288.3	89.4	**396.0**	0.67
Pervious MDI (pur_MDI)	0.4	4.1	0.8	**5.3**	0.67
Pervious HDI (pur_HDI)	0.0	0.1	0.0	**0.1**	0.66
Impervious LDI (imp_LDI)	15.0	312.7	87.8	**415.5**	14.19
Impervious MDI (imp_MDI)	31.0	446.7	81.9	**559.5**	70.78
Impervious HDI (imp_HDI)	0.0	45.4	0.0	**45.4**	73.19
Septic Systems	347.4	2,442.4	4,506.6	**7,296.5**	
Channel Erosion	3.0	0.3	0.6	**3.9**	
Groundwater	4,943.5	9,725.1	5,488.5	**20,157.1**	
Total Nitrogen Load	6,610.0	27,859.8	14,643.1	**49,112.9**	

In Tables 5-5 and 5-6, sub-watershed loads were calculated based on the sources contributing from each unique stream segment and its contributing drainage area, exclusive of in-stream contributions received from upstream sub-watersheds. Total loads from all upstream segments may not be directly additive to calculate total downstream loads, because differential delivery factors (representative of in-stream attenuation) would apply to smaller upstream areas than to larger downstream watersheds which receive in-stream loads from other stream segments.

Chapter 6: TMDL ALLOCATIONS

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that appropriate actions can be taken to achieve water quality standards (USEPA, 1991). The stressor analysis in Turley Creek indicated that sediment was the "most probable stressor" in the watershed, and therefore, sediment will serve as the basis for development of the TMDL. In the Long Meadow Run watershed, the stressor analysis indicated nutrients, organic matter, and sediment as stressors. However, since bacteria reductions called for in the bacteria TMDL for the North Fork Shenandoah River will already reduce particulate nutrients and organic matter and encompass the Long Meadow Run watershed, the TMDLs in the Long Meadow Run watershed will be developed only for nitrogen and sediment.

The AllForX approach was used to set appropriate sediment and nitrogen TMDL endpoints and to quantify the margin of safety (MOS) for each TMDL watershed. Separate AllForX sediment regressions were developed for each of the watersheds, and an AllForX nitrogen regression was developed for Long Meadow Run, along with the selected comparison watersheds. The detailed AllForX endpoint calculations are in Appendix F.

6.1. Sediment TMDLs (Long Meadow Run and Turley Creek)

6.1.1. TMDL Components

The sediment TMDL for each watershed was calculated, and its components distributed, using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where $\sum WLA$ = sum of the wasteload (permitted) allocations;

$\sum LA$ = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

The sediment TMDL was based on the value of the AllForX threshold, the point on the regression line where VSCI equals 60, the biological impairment threshold. The sediment TMDL load of each TMDL watershed was calculated as the respective AllForX threshold value times its all-forest sediment load. The AllForX endpoint for the Long Meadow Run watersheds was 21.0 (Figure 4-3), while the AllForX endpoint for the Turley Creek watershed was 9.72 (Figure 4-2). Details of the derivation of AllForX for the TMDL and comparison watersheds are provided in Appendix F.

The WLA in each watershed is comprised of sediment loads from individual industrial stormwater and commercial permitted sources, as well as aggregated loads from construction runoff in each watershed. In addition, a Future Growth WLA was calculated as 1% of the TMDL.

An explicit MOS for each TMDL watershed was also calculated using the AllForX method. The 80% confidence interval was developed around the chosen value of AllForX, based on the number of watersheds included in the regression and the standard deviation of their AllForX values. The MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest sediment load for each watershed, amounting to 11.9% of the TMDL for the Long Meadow Run watershed, and 7.4% for the Turley Creek watershed.

The LA was calculated as the TMDL minus the sum of WLA and MOS. The TMDL load and its components for each TMDL watershed are shown in Table 6-1.

In Table 6-1, TMDL loads were calculated based on the sources contributing from each unique stream segment and its contributing drainage area, exclusive of in-stream contributions received from upstream watersheds.

Table 6-1. Sediment TMDLs and Components (tons/yr) for Long Meadow Run and Turley Creek

<table>
<tr><th rowspan="2">Impairment</th><th>TMDL</th><th colspan="2">WLA</th><th>LA</th><th>MOS</th></tr>
<tr><th colspan="5">(tons/yr)</th></tr>
<tr><td colspan="6">Cause Code Group B45R-01-BEN</td></tr>
<tr><td rowspan="4">Long Meadow Run
VAV-B45R_LOM01A00</td><td rowspan="4">1,766.4</td><td colspan="2">27.92</td><td rowspan="4">1,527.7</td><td rowspan="4">210.8</td></tr>
<tr><td>aggregate construction =</td><td>10.05 tons/yr</td></tr>
<tr><td>aggregate SFH permits =</td><td>0.21 tons/yr</td></tr>
<tr><td>Future Growth WLA =</td><td>17.66 tons/yr</td></tr>
<tr><td colspan="6">Cause Code Group B45R-02-BEN</td></tr>
<tr><td rowspan="5">Turley Creek
VAV-B45R_TRL01A00
VAV-B45R_TRL02A00</td><td rowspan="5">926.8</td><td colspan="2">19.87</td><td rowspan="5">838.2</td><td rowspan="5">68.7</td></tr>
<tr><td>aggregate construction =</td><td>3.65 tons/yr</td></tr>
<tr><td>aggregate ISWGP Permits (VAG840133, VAR050808)</td><td>6.86 tons/yr</td></tr>
<tr><td>aggregate SFH permits =</td><td>0.08 tons/yr</td></tr>
<tr><td>Future Growth WLA =</td><td>9.27 tons/yr</td></tr>
</table>

6.1.2. Maximum Daily Loads for Sediment

The USEPA has mandated that TMDL studies submitted since 2007 include a maximum “daily” load (MDL), in addition to the average annual load shown in Section 6.1 (USEPA, 2006a). The approach used to develop the MDL was provided in Appendix B of a related USEPA guidance document (USEPA, 2006b). This appendix entitled “Approaches for developing a Daily Load Expression for TMDLs computed for Longer Term Averages” is dated December 15, 2006. This guidance provides a procedure for calculating an MDL (tons/day) for each watershed from the standard deviation and the coefficient of variation (CV) based on annual loads over a period of time for the long-term average (LTA) annual TMDL load (tons/yr). The “LTA to MDL multiplier” (X) for each of the four watersheds was calculated from the 2002-2010 simulated output of total annual sediment load, using the following equation in Microsoft Excel:

X = exp(2.778*sqrt(ln(power(CV,2)+1))-0.5*ln(power(CV,2)+1)).

A summary of the statistics and resulting “LTA to MDL multiplier” are shown in Table 6-2.

Table 6-2. "LTA to MDL multiplier" Statistics

Annual Load Measures	Long Meadow Run	Turley Creek
	English tons/yr	
Minimum Annual Load	528	210
Maximum Annual Load	13,281	4,740
Standard Deviation	3,176	1,138
Average Annual Load	4,152	1,444
	Unitless	
Coefficient of Variation	0.7651	0.7881
"LTA to MDL" Multiplier	5.235	5.416

Based on Table B-1 (USEPA, 2006a)

The standard deviation and coefficient of variation (CV) are measures of the range of annual sediment load. The "LTA to MDL" multiplier was calculated from the USEPA guidance. The MDL was calculated as the TMDL divided by 365 days/yr and multiplied by the "LTA to MDL" multiplier.

Since the WLA represents permitted loads, no multiplier was applied to these loads. Therefore the daily WLA and components were converted to daily loads by dividing by 365 days/yr. The daily LA was calculated as the MDL minus the daily WLA minus the daily MOS. The resulting sediment MDL and associated components for the Long Meadow Run and Turley Creek impaired segments are shown in Table 6-3 in units of tons/day.

Expressing the TMDL as a daily load does not interfere with a permit writer's authority under the regulations to translate that daily load into the appropriate permit limitation, which in turn could be expressed as an hourly, weekly, monthly or other measure (USEPA, 2006a).

Table 6-3. Maximum "Daily" Sediment Loads and Components (tons/day) for Long Meadow Run and Turley Creek

Impairment	MDL	WLA		LA	MOS
	(tons/day)				
Cause Code Group B45R-					
Long Meadow Run	25.34	0.076		21.91	3.35
VAV-B45R_LOM01A00		aggregate construction =	0.0275 tons/day		
		aggregate SFH permits =	0.0006 tons/day		
		Future Growth WLA =	0.0484 tons/day		
Cause Code Group B45R-					
Turley Creek	13.76	0.054		12.69	1.02
VAV-B45R_TRL01A00		aggregate construction =	0.01 tons/day		
VAV-B45R_TRL02A00		aggregate ISWGP Permits (VAG840133, VAR050808)	0.0188 tons/day		
		aggregate SFH permits =	0.0002 tons/day		
		Future Growth WLA =	0.0254 tons/day		

6.1.3. Sediment Allocation Scenarios

The target load for the allocation scenario in each watershed is the TMDL minus the MOS. Both the TMDL and MOS were quantified using the AllForX methodology, discussed in Section 6.1.

Sediment loads were simulated with GWLF using a 2007 BMP scenario. These Existing Loads were then adjusted based on load reductions from BMPs that have been installed in the watersheds through 12/31/09 as the baseline Existing Loads that correspond with the weather and landuse inputs. A summary of BMPs installed and active as of 12/31/2009 are detailed in Appendix G.

Two allocation scenarios were created for each watershed. In each scenario, Forest and Permitted WLAs were not subjected to reductions. Areas of harvested forest and construction are transient sources of sediment subject to existing regulations. Their reduction efficiencies were currently estimated as only half of those possible. Both allocation scenarios assume that these practices will meet their potential reduction efficiencies with better enforcement of existing regulations. In addition, the first allocation scenario assumed equal percent reductions from all other sources, while in the second scenario, higher percent reductions were required from the largest sources (Row Crops and Pasture) with lower percent reductions from the other sources. Allocation scenarios are detailed in Table 6-4 and 6-7 for Long Meadow Run and Turley Creek watersheds, respectively.

The 2007 BMP Scenario Load is shown at the top of each table for comparison with the 2009 baseline Existing Sediment Load, as shown within the table. Beneath each table is shown the Target Allocation Load (TMDL – MOS – future growth (FG)), and the Needed Load Reduction, both as an amount and as a % of the Existing Load.

Existing BMPs that addressed Channel Erosion were credited using the latest Chesapeake Bay TMDL load reduction rates of 44.88 lbs of sediment/linear foot of stream restoration (Schueler and Stack, 2013) and distributed proportionally among the land-based sources.

The Local Steering Committee preferred Scenario 2 as being the more appropriate starting point around which to build an Implementation Plan for achieving sediment reductions from both the Long Meadow Run and Turley Creek watersheds.

Table 6-4. Long Meadow Run: Sediment TMDL Load Allocation Scenario

2007 BMP Load = (tons/yr) 3,624.1

Land Use/ Source Group	Area (acres)	2009 Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Load (tons/yr)	% Reduction	Load (tons/yr)
Row Crops	848.6	481.6	53.4%	224.5	58.0%	202.3
Pasture	5,419.4	2,104.5	53.4%	981.0	58.0%	883.9
Riparian Pasture	139.7	304.4	53.4%	141.9	58.0%	127.9
Hay	1,154.9	299.6	53.4%	139.7	15.5%	253.2
Forest	1,663.7	15.8	0.0%	15.8	0.0%	15.8
Harvested Forest	16.7	1.0	41.3%	0.6	41.3%	0.6
Developed, impervious	37.8	7.8	53.4%	3.6	15.5%	6.6
Developed, pervious	600.2	42.8	53.4%	19.7	15.5%	35.9
Transitional	6.4	16.7	39.8%	10.0	39.8%	10.0
Channel Erosion		1.8	53.4%	0.8	15.5%	1.5
Permitted WLA				0.21		0.21
Total Load		**3,276.06**		**1,537.91**		**1,537.91**

TMDL - MOS - FG = (tons/yr) **1,537.91**
Needed Reduction = (tons/yr) 1,738.15
% Reduction Needed = (%) 53.1%

= WLA components

Permitted VPDES and ISWGP impervious loads were subtracted from "Developed, impervious" loads.
Permitted ISWGP pervious and Septic system loads were subtracted from "Developed, pervious" loads.
Channel erosion reduction credits are distributed proportionately from all land-based sources.

Table 6-5. Turley Creek: Sediment TMDL Load Allocation Scenario

2007 BMP Load = (tons/yr) 1,225.1

Land Use/ Source Group	Area (acres)	2009 Sediment Load (tons/yr)	Scenario 1		Scenario 2	
			% Reduction	Load (tons/yr)	% Reduction	Load (tons/yr)
Row Crops	220.3	154.2	31.8%	105.2	34.0%	101.76
Pasture	1,673.2	751.6	31.8%	512.9	34.0%	496.02
Riparian Pasture	46.6	125.9	31.8%	85.9	34.0%	83.08
Hay	309.5	76.5	31.8%	52.2	9.2%	69.40
Forest	3,443.8	68.6	0.0%	68.6	0.0%	68.61
Harvested Forest	34.8	4.28	42.9%	2.4	42.9%	2.45
Developed, impervious	11.3	3.0	31.8%	-0.1	9.2%	0.58
Developed, pervious	273.9	20.54	31.8%	9.2	9.2%	13.82
Transitional	2.9	6.3	41.7%	3.7	41.7%	3.65
Channel Erosion		2.8	31.8%	1.9	9.2%	2.55
Permitted WLA				6.9		6.94
Total Load		**1,213.6**		**848.88**		**848.88**

TMDL - MOS - FG = (tons/yr) **848.88**

Needed Reduction = (tons/yr) 364.68 = WLA components

% Reduction Needed = (%) 30.1%

Permitted VPDES and ISWGP impervious loads were subtracted from "Developed, impervious" loads.

Permitted ISWGP pervious and Septic system loads were subtracted from "Developed, pervious" loads.

6.2. Nitrogen TMDL (Long Meadow Run)

6.2.1. TMDL Components

The nitrogen TMDL for Long Meadow Run watershed was calculated, and its components distributed, using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where $\sum$WLA = sum of the wasteload (permitted) allocations;

$\sum$LA = sum of load (nonpoint source) allocations; and

MOS = margin of safety.

Similar to the procedure for sediment, a regression was created between all-forested nitrogen loads and VSCI values for the same set of comparison watersheds. The nitrogen TMDL AllForX threshold was set as the value of AllForX at the point on the regression line where VSCI equals 60, the biological impairment threshold. The nitrogen TMDL load for Long Meadow Run watershed was calculated as the AllForX threshold value times its all-forest nitrogen load. The AllForX threshold value for the Long Meadow Run watersheds was 4.10 (Figure 4-4). Details of the derivation of AllForX for the nitrogen TMDL and comparison watersheds are provided in Appendix F.

The WLA in each watershed is comprised of nitrogen loads from individual industrial stormwater and commercial permitted sources and septic systems, as well as aggregated loads from construction runoff in each watershed. WLAs for aggregate construction and septic systems were calculated from the selected allocation scenario by applying the equal percent reduction required from all non-permitted or excluded sources to their respective existing Transitional and Septic System loads. In addition, a Future Growth WLA was calculated as 1% of the TMDL.

An explicit MOS for the Long Meadow Run watershed was also calculated using the AllForX method. The 80% confidence interval was developed around the chosen value of AllForX, based on the number of watersheds included in the regression and the standard deviation of their AllForX values. The MOS was set equal to the difference between the value of AllForX at VSCI = 60 and the value of AllForX at the lower confidence interval limit, multiplied times the all-forest nitrogen load for the watershed, amounting to 11.0% of the TMDL for the Long Meadow Run watershed.

The LA was calculated as the TMDL minus the sum of WLA and MOS. The nitrogen TMDL load and its components for each TMDL watershed are shown in Table 6-1.

In Table 6-1, nitrogen TMDL loads were calculated based on the sources contributing from each unique stream segment and its contributing drainage area, exclusive of in-stream contributions received from upstream watersheds.

Table 6-6. Nitrogen TMDL and Components (lbs/yr) for Long Meadow Run

<table>
<tr><th rowspan="2">Impairment</th><th>TMDL</th><th colspan="2">WLA</th><th>LA</th><th>MOS</th></tr>
<tr><th colspan="5">(lbs/yr)</th></tr>
<tr><td colspan="6">Cause Code Group B45R-01-BEN</td></tr>
<tr><td rowspan="4">Long Meadow Run
VAV-B45R_LOM01A00</td><td rowspan="4">19,532.1</td><td colspan="2">520.6</td><td rowspan="4">16,866.7</td><td rowspan="4">2,144.8</td></tr>
<tr><td>aggregate construction =</td><td>20.7 lbs/yr</td></tr>
<tr><td>aggregated SFH WLA =</td><td>304.6 lbs/yr</td></tr>
<tr><td>Future Growth WLA =</td><td>195.3 lbs/yr</td></tr>
</table>

6.2.2. Maximum Daily Loads for Nitrogen

The Maximum Daily Loads (MDLs) for nitrogen were calculated in an identical fashion as for sediment, outlined in Section 6.1.2.

The resulting nitrogen MDL and associated components for the Long Meadow Run and Turley Creek impaired segments are shown in Table 6-7 in units of lbs/day.

Expressing the TMDL as a daily load does not interfere with a permit writer's authority under the regulations to translate that daily load into the appropriate permit limitation, which in turn could be expressed as an hourly, weekly, monthly or other measure (USEPA, 2006a).

Table 6-7. Maximum "Daily" Sediment Loads and Components (tons/day) for Long Meadow Run

Impairment	MDL	WLA	LA	MOS
	(lbs/day)			
Cause Code Group B45R-01-BEN				
Long Meadow Run	280.14	1.426	241.91	36.80
VAV-B45R_LOM01A00		aggregate construction = 0.057 lbs/day		
		aggregated SFH WLA = 0.835 lbs/day		
		Future Growth WLA = 0.535 lbs/day		

6.2.3. Nitrogen Allocation Scenarios

The target load for the allocation scenario in the Long Meadow Run watershed is the TMDL minus the MOS. Both the TMDL and MOS were quantified using the AllForX methodology, discussed in Section 6.2.1.

Nitrogen loads were simulated with GWLF as a 2007 BMP scenario. The 2009 baseline Existing Loads were then calculated by adjusting the 2007 BMP Scenario loads to reflect the estimated load reductions from BMPs that have been installed in the watersheds through 2009 and that correspond with the weather and landuse inputs. A summary of BMPs installed and active as of 12/31/2009 are detailed in Appendix G.

Although groundwater was initially simulated as a separate source to emphasize its important contribution to stream nitrogen loads, in reality the nitrogen in groundwater arises from management practices associated with individual landuses, and can best be reduced through improved management practices on those landuses. In order to make this link more explicit, the groundwater nitrogen load was distributed among the pervious landuses in each watershed based on the simulated ratio of groundwater N to runoff N and the relative area of each landuse. For this purpose, simulated output from the A51165PS2_5560_5100 land-river segment in the Chesapeake Bay Watershed Model Phase 5.3.2 was used with average annual NO23 used to represent groundwater N and average annual OrgN used to represent surface runoff N. Although this is only an approximation of the groundwater and runoff loads, it appeared to be a reasonable means of distributing groundwater N among the landuses. More details are included in Appendix I.

Two allocation scenarios were created for each watershed. In each scenario, Forest and Permitted WLAs were not subjected to reductions. Areas of harvested forest and construction are transient sources of nitrogen subject to existing regulations. Their reduction efficiencies were currently estimated as only half of those possible. Both allocation scenarios assume that these practices will meet their potential reduction efficiencies with better enforcement of existing regulations. In addition, the first allocation scenario assumed equal percent reductions from all other sources, while in the second scenario, higher reductions were required from the largest land-based sources (Row Crops and Pasture) with lower % reductions from the other sources. Allocation scenarios are detailed in Table 6-8 for Long Meadow Run.

The 2007 BMP Scenario Load is shown at the top of the table for comparison with the 2009 baseline Existing Nitrogen Load, as shown within the table. Beneath the table is shown the Target Allocation Load (TMDL – MOS – Future Growth (FG)), and the Needed Reduction, both as an amount and as a % of Existing Load.

Existing BMPs that addressed Channel Erosion were credited using the latest Chesapeake Bay TMDL load reduction rates of 0.075 lbs of nitrogen/linear foot of stream restoration (Schueler and Stack, 2013).

The Local Steering Committee preferred Scenario 2 as being the more appropriate starting point around which to build an Implementation Plan for achieving nitrogen reductions from the Long Meadow Run watershed.

Table 6-8. Long Meadow Run: Nitrogen TMDL Load Allocation Scenarios

2007 BMP Load = (lbs/yr) 49,112.9

Land Use/ Source Group	Area (acres)	2009 Nitrogen Load (lbs/yr)	Scenario 1		Scenario 2	
			Reduction	Load (lbs/yr)	Reduction	Load (lbs/yr)
Row Crops	848.6	3,795.9	66.2%	1,284.0	75.0%	949.0
Pasture	5,419.4	27,355.0	66.2%	9,253.2	75.0%	6,838.8
Riparian Pasture	139.7	1,172.2	66.2%	396.5	75.0%	293.1
Hay	1,154.9	5,444.0	66.2%	1,841.5	46.2%	2,930.1
Forest	1,663.7	1,080.9	0.0%	1,080.9	0.0%	1,080.9
Harvested Forest	16.7	38.4	32.9%	25.8	32.9%	25.8
Developed, impervious	37.8	1,014.9	66.2%	343.3	46.2%	546.2
Developed, pervious	600.2	813.2	66.2%	275.1	46.2%	437.7
Transitional	6.4	20.7	0.0%	20.7	0.0%	20.7
Septic Systems						
non-discharging		7,296.5	66.2%	2,365.1	46.2%	3,763.1
permitted				304.6		304.6
Channel Erosion		3.9	66.2%	1.3	46.2%	2.1
Total Load		**48,035.7**		**17,192.0**		**17,192.0**

TMDL - MOS - FG = (lbs/yr) **17,192.0**
Needed Reduction = (lbs/yr) 30,843.7
% Reduction Needed = (%) 64.2%

= WLA components

Permitted ISWGP impervious loads were subtracted from "Developed, impervious" loads.
Permitted ISWGP pervious loads were subtracted from "Developed, pervious" loads.
Pre-2009 channel erosion reduction credits were distributed proportionately from all land-based sources.

Chapter 7: TMDL IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the benthic impairments on Turley Creek and Long Meadow Run. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by State Water Control Board (SWCB) and then the USEPA measures must be taken to reduce pollutant levels in the stream. These measures, which can include the use of better treatment technology and the installation of BMPs, are implemented in an iterative process that is described along with specific BMPs in the Implementation Plan. The process for developing an Implementation Plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of Implementation Plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved Implementation Plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

DCR and DEQ will work closely with watershed stakeholders, interested state agencies, and support groups to develop an acceptable Implementation Plan that will result in meeting the water quality target. Stream delisting of Turley Creek and Long Meadow Run will be based on biological health and not on numerical pollution loads.

7.1. Staged Implementation

Implementation of BMPs in these watersheds will occur in stages. The benefit of staged implementation is that it provides a mechanism for developing public support and for evaluating the efficacy of the TMDL in achieving the water quality standard.

In general, Virginia intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. Among the sediment sources identified in the Turley Creek and Long Meadow Run watersheds, the following BMPs should be useful in effecting the necessary reductions: livestock stream exclusion, riparian buffers, and grazing land management. The major sources of nitrogen in the Long Meadow Run watershed are groundwater and storm water runoff/infiltration from areas receiving manure and other nutrient fertilizers.

The iterative implementation of BMPs in these watersheds has several benefits:

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

Watershed stakeholders will have opportunity to participate in the development of the TMDL Implementation Plan. Specific goals for BMP implementation will be established as part of the Implementation Plan development.

7.2. Link to ongoing Restoration Efforts

Implementation of BMPs to address the benthic impairments in Turley Creek and Long Meadow Run will be coordinated with BMPs required to meet bacteria water quality standards in a previous TMDL developed for the North Fork Shenandoah River watershed, which includes both Turley Creek and Long Meadow Run.

7.3. Reasonable Assurance for Implementation

7.3.1. TMDL Monitoring

DEQ will continue monitoring benthic macroinvertebrates and habitat in Turley Creek in accordance with its biological monitoring program, and TSS in accordance with its ambient monitoring program at station 1BTRL000.02. DEQ will continue monitoring benthic macroinvertebrates and habitat in Long Meadow Run at station 1BLOM000.24 in accordance with its biological monitoring program, and TN and TSS at station 1BLOM001.45 in accordance with its ambient monitoring program. DEQ will continue to use data from these monitoring stations to evaluate improvements in the benthic community and the effectiveness of TMDL implementation in attainment of the general water quality standard.

7.3.2. TMDL Modeling

If in a future review, the reductions called for in these TMDLs based on current modeling are found to be insufficiently protective of local water quality, then revision(s) will be made as necessary to provide reasonable assurance that water quality goals will be achieved.

7.3.3. Regulatory Framework

Federal Regulations

While section 303(d) of the Clean Water Act and current USEPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and wasteload allocations can and will be implemented. Federal regulations also require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to USEPA for review.

State Regulations

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-

44.19.7). WQMIRA also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process and implementation plan development, especially those implemented through water quality based effluent limitations. However, those requirements that are considered BMPs may be enhanced by inclusion in the TMDL IP, and their connection to the targeted impairment. New permitted point source discharges will be allowed under the waste load allocation provided they implement applicable VPDES requirements.

7.3.4. Implementation Funding Sources

Implementation funding sources will be determined during the implementation planning process by the local watershed stakeholder planning group with assistance from DEQ and DCR. Potential sources of funding include Section 319 funding for Virginia's Nonpoint Source Management Program, the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund, although other sources are also available for specific projects and regions of the state. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

7.3.5. Reasonable Assurance Summary

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by regional and local offices of DEQ, DCR, and other cooperating agencies.

Once developed, DEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between USEPA and DEQ, DEQ also submitted a draft Continuous Planning Process to USEPA in which DEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

Taken together, the follow-up monitoring, WQMIRA, public participation, the Continuing Planning Process, the reductions called for in the concurrent bacteria TMDL on the North Fork Shenandoah River, and the planned continuation into the implementation phase comprise a reasonable assurance that the Turley Creek sediment TMDL and the Long Meadow Run nitrogen and sediment TMDLs will be implemented and water quality will be restored.

Chapter 8: PUBLIC PARTICIPATION

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made.

An initial visit and watershed tour was coordinated with the local Shenandoah Valley Soil and Water Conservation District and NRCS personal on November 8, 2010.

The first Local Steering Committee Meeting was held on October 3, 2011 at the DEQ Valley Regional Office in Harrisonburg, Virginia. The purpose of that meeting was to introduce agency stakeholders to the TMDL process and to discuss the impairments identified on stream segments in these watersheds. The public meeting was attended by 12 people.

The first Public Meeting followed by a second Local Steering Committee meeting was held at the J. Frank Hillyard Middle School in Broadway, Virginia on November 16, 2011, where the results from the stressor analysis were presented, and comments were solicited from the stakeholder group. The LSC meeting was attended by 21 people.

A third Local Steering Committee meeting was held on January 25, 2012, also at the J. Frank Hillyard Middle School in Broadway. The draft TMDL report was presented to LSC committee members for comment prior to the final public meeting. The third LSC meeting was attended by 30 people.

A public meeting to present the initial draft TMDL report on Turley Creek and Long Meadow Run for their benthic impairments was held on March 21, 2012 also at the J. Frank Hillyard Middle School in Broadway. This final TMDL public meeting was attended by 18 stakeholders and served as the initiation of the TMDL implementation planning phase, which is a continuation of this project. The public comment period ended on April 25, 2012.

Since the original TMDL was rejected by EPA, another series of meetings was held during the current revision phase to re-open the TMDL starting in June 2014 in order to address EPA comments and to re-submit the TMDL. The first Local Steering

Committee meeting during this revision phase was held on July 24, 2014 at the Shenandoah Valley Soil and Water Conservation District office in Harrisonburg, Virginia, where an update was presented on the status of the previous Long Meadow Run TMDLs for sediment and nitrogen and the Turley Creek TMDL for sediment, some planned sediment and nitrogen TMDL endpoint and modeling revisions, followed by discussion on how best to elicit public participation during the revision phase. A total of 17 people were in attendance at this LSC meeting.

The next LSC meeting was held March 25, 2015 at the Massanutten Regional Library. The Local Steering Committee discussed the draft TMDL report, including the TMDLs, existing sediment and nitrogen loads, and allocation scenarios to meet the individual TMDLs. The stakeholders agreed that a public meeting to mark the completion of the TMDL and Implementation Plan could feature food in some way, possibly an ice cream social or barbeque contest in September. The group agreed to meet one additional time to review the TMDL and IP documents and review BMP and cost estimates and strategies.

The third LSC meeting was held July 20, 2015 again at the Library. The Committee reviewed a “Where we’ve been” overview and agreed that EPA should take a “provisional review” of the TMDL document before the public meeting, which will cover both the TMDL and IP documents. The group discussed the relative cost effectiveness of BMPs and added to the already comprehensive list of BMPs that would be applicable in these watersheds. The group agreed to meet one last time to plan the public meeting for September.

The fourth and final LSC meeting was again held at the Library on August 12, 2015. The latest updates to the model were reviewed with the group. These updates included using the Chesapeake Bay TMDL model N loads categorized by land use to develop ratios for nitrogen runoff and then applied to the watersheds by landuse. The overall TMDL goal was the same, but it has a better and more accurate connection the IP development and BMP selections. The committee decided to have the public meeting to introduce both the TMDL and the IP at a public meeting on September 14, 2015 and a participant offered to host locally made donuts for that meeting. The group reviewed outreach methods and other essential elements of the public meeting.

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Appendix A: Glossary of Terms

Allocation
That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario
A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution.

Best Management Practices (BMP)
Methods, measures, or practices that are determined to be reasonable and cost- effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Direct nonpoint sources
Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

Hydrology
The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.

Load allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

Model
Mathematical representation of hydrologic and water quality processes. Effects of Land use, slope, soil characteristics, and management practices are included.

Nonpoint source
Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution
Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach
Segment of a stream or river.

Runoff
That part of rainfall or snowmelt that runs off the land into streams or other surface water. It can carry pollutants from the air and land into receiving waters.

Simulation
The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Total Maximum Daily Load (TMDL)
The sum of the individual wasteload allocations (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff
Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.

Wasteload allocation (WLA)
The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard
Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed
A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.
http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.
http://www.ext.vt.edu/pubs/bse/442-550/442-550.html.

Appendix B: Detailed Land Use Distributions

Table B-1. Land Use Distributions in Long Meadow Run and Turley Creek Watersheds

Modeled Land Use/Source Categories	LOM1 Lower Long Meadow Run	LOM2 Upper Long Meadow Run	LOM3 Unnamed Tributary	LOM1x Long Meadow Run Total	TRL1 Lower Turley Creek	TRL2 Upper Turley Creek	TRL3 Brock Creek	TRL1x Turley Creek Total
	Area in acres							
HiTill Rowcrop (hit)	18.2	190.6	69.9	278.7	25.0	30.9	5.8	61.7
LoTill Rowcrop (lot)	48.6	508.5	186.4	743.5	66.8	82.3	15.5	164.6
Pasture (pas_g)	30.9	382.5	124.4	537.8	41.6	67.2	57.3	166.0
Pasture (pas_f)	200.8	2,486.0	808.8	3,495.6	270.3	436.7	372.1	1,079.2
Pasture (pas_p)	77.2	956.2	311.1	1,344.4	104.0	168.0	143.1	415.1
Riparian pasture (trp)	8.7	107.5	35.0	151.1	11.7	18.9	16.1	46.6
AFO (afo)	2.4	29.6	9.6	41.6	3.2	5.2	4.4	12.9
Hay (hay)	56.5	699.1	227.4	983.0	76.0	122.8	104.7	303.5
Forest (for)	5.8	1,341.8	303.1	1,650.6	387.1	419.1	2,637.6	3,443.8
Harvested forest (hvf)	0.1	13.6	3.1	16.7	3.9	4.2	26.6	34.8
Transitional (barren)	0.3	4.6	1.6	6.4	0.5	1.0	1.5	2.9
Pervious LDI (pur_LDI)	23.7	417.0	151.4	592.1	42.8	92.6	136.2	271.7
Pervious MDI (pur_MDI)	0.5	6.1	1.3	7.9	0.0	0.4	1.5	1.9
Pervious HDI (pur_HDI)	0.0	0.2	0.0	0.2	0.0	0.0	0.3	0.3
Impervious LDI (imp_LDI)	1.2	21.2	6.8	29.3	2.0	1.6	4.6	8.2
Impervious MDI (imp_MDI)	0.5	6.1	1.3	7.9	0.0	0.4	1.5	1.9
Impervious HDI (imp_HDI)	0.0	0.6	0.0	0.6	0.0	0.0	1.2	1.2
Total Simulated Area	**475.4**	**7,170.9**	**2,241.2**	**9,887.5**	**1,034.7**	**1,451.3**	**3,530.2**	**6,016.3**
Water	1.6	0.0	0.0	1.6	1.9	0.0	10.8	12.7
Total Area	477.0	7,170.9	2,241.2	9,889.1	1,036.6	1,451.3	3,541.1	6,029.0

Table B-2. Land Use Distributions in Comparison Watersheds

Modeled Land Use/Source Categories	AllForX Comparison Watersheds										
	Brock Creek	Beaver Creek	Cedar Run	Cub Run	Laurel Run	Lewis Creek	Little Stony Creek	Moffett Creek	Mill Run	Naked Creek	North River
	Area in acres										
HiTill Rowcrop (hit)	5.8	12.4	0.0	8.9	0.0	27.7	3.8	5.3	230.9	69.7	0.0
LoTill Rowcrop (lot)	15.5	33.1	0.0	21.7	0.0	83.8	2.2	16.0	133.2	179.7	0.0
Pasture (pas_g)	57.3	16.9	0.4	23.0	2.3	126.6	21.9	73.3	245.9	212.8	2.0
Pasture (pas_f)	372.1	109.7	2.7	149.5	14.8	823.1	142.1	476.2	1,598.5	1,383.5	13.3
Pasture (pas_p)	143.1	42.2	1.1	57.5	5.7	316.6	54.6	183.2	614.8	532.1	5.1
Riparian pasture (trp)	16.1	4.8	0.1	8.3	0.6	35.8	6.1	20.7	69.1	76.4	0.6
AFO (afo)	4.4	0.8	0.0	1.2	0.1	5.8	1.3	3.4	19.0	11.0	0.1
Hay (hay)	104.7	30.8	0.8	42.2	4.1	230.8	39.9	133.5	449.5	391.0	3.7
Forest (for)	2,637.6	4,942.1	3,065.2	9,015.5	3,006.2	521.5	7,545.2	10,186.3	4,693.2	23,355.2	10,492.6
Harvested forest (hvf)	26.6	49.9	31.0	91.1	30.4	5.3	76.2	102.9	47.4	235.9	106.0
Transitional (barren)	1.5	1.5	0.0	3.0	1.1	3.1	3.7	6.2	4.3	13.9	3.1
Pervious LDI (pur_LDI)	136.2	144.8	0.0	298.4	111.8	282.0	369.0	606.0	411.9	1,327.3	306.0
Pervious MDI (pur_MDI)	1.5	1.2	0.0	0.0	0.0	3.5	0.0	1.4	2.3	5.4	0.0
Pervious HDI (pur_HDI)	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0
Impervious LDI (imp_LDI)	4.6	3.9	0.0	2.5	0.0	18.9	0.9	4.7	4.8	37.9	0.0
Impervious MDI (imp_MDI)	1.5	1.2	0.0	0.0	0.0	3.5	0.0	1.4	2.3	5.4	0.0
Impervious HDI (imp_HDI)	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0
Total Simulated Area	**3,530.2**	**5,395.2**	**3,101.3**	**9,722.7**	**3,177.1**	**2,488.0**	**8,267.0**	**11,820.5**	**8,527.4**	**27,842.2**	**10,932.6**
Water	7.0	0.0	0.0	0.0	0.0	6.2	0.8	3.1	0.8	0.0	10.8
Total Area	3,537.2	5,395.2	3,101.3	9,722.7	3,177.1	2,494.2	8,267.8	11,823.6	8,528.1	27,842.2	10,943.4

Appendix C: Detailed Simulated Sediment Loads

Table C-1. Simulated Sediment Loads for AllForX Modeling in Long Meadow Run and Turley Creek Watersheds

Land Use/Source Categories	TMDL Watersheds	
	Long Meadow Run Total	**Turley Creek Total**
	LOM1x	**TRL1x**
	Sediment Load in metric tons/yr	
HiTill Rowcrop (hit)	403.5	90.5
LoTill Rowcrop (lot)	253.7	57.1
Pasture (pas_g)	29.8	10.0
Pasture (pas_f)	1,021.4	351.0
Pasture (pas_p)	908.3	305.2
Riparian pasture (trp)	340.3	114.2
AFO (afo)	46.7	15.6
Hay (hay)	193.8	66.7
Forest (for)	14.4	62.2
Harvested forest (hvf)	1.4	5.5
Transitional (barren)	26.0	9.5
Pervious LDI (pur_LDI)	39.1	18.5
Pervious MDI (pur_MDI)	0.4	0.1
Pervious HDI (pur_HDI)	0.0	0.0
Impervious LDI (imp_LDI)	4.2	1.5
Impervious MDI (imp_MDI)	2.8	0.7
Impervious HDI (imp_HDI)	0.2	0.5
Channel Erosion	1.7	2.6
Point Sources		
Existing Sediment Load	**3,287.8**	**1,111.4**
All-Forested Sediment Load	**76.4**	**86.5**
AllForX	**43.0**	**12.8**

Table C-2. Simulated Sediment Loads for AllForX Modeling in Comparison Watersheds

Land Use/Source Categories	AllForX Comparison Watersheds										
	Brock Creek	**Beaver Creek**	**Cedar Run**	**Cub Run**	**Laurel Run**	**Lewis Creek**	**Little Stony Creek**	**Moffett Creek**	**Mill Run**	**Naked Creek**	**North River**
	TRL3	**BVR**	**CDR**	**CUB**	**LAR**	**LEW**	**LSC**	**MFT**	**MIL**	**NAK**	**NTH**
	Sediment Load in metric tons/yr										
HiTill Rowcrop (hit)	7.7	3.5	0.0	6.7	0.0	65.1	1.3	8.9	74.3	26.9	0.0
LoTill Rowcrop (lot)	4.9	2.1	0.0	3.8	0.0	45.3	0.2	6.2	9.2	16.5	0.0
Pasture (pas_g)	4.3	0.3	0.0	0.9	0.1	12.8	0.6	7.0	2.2	4.5	0.0
Pasture (pas_f)	143.0	9.5	0.2	30.7	5.5	403.7	24.3	211.6	71.8	140.1	0.8
Pasture (pas_p)	119.5	9.6	0.2	29.2	5.5	338.6	22.6	169.8	112.9	118.5	1.1
Riparian pasture (trp)	44.6	8.0	0.2	36.5	1.0	52.8	4.4	111.3	1.4	146.5	1.1
AFO (afo)	6.0	0.7	0.0	2.7	0.1	4.3	0.5	8.7	0.3	10.6	0.1
Hay (hay)	27.2	1.8	0.0	6.3	1.1	76.2	4.7	41.0	14.4	27.2	0.2
Forest (for)	54.8	22.6	15.4	110.1	18.3	9.5	63.2	280.9	7.8	460.5	34.9
Harvested forest (hvf)	4.8	2.1	1.2	9.6	1.7	0.8	6.0	23.7	0.7	36.7	4.4
Transitional (barren)	4.0	1.8	0.0	8.5	2.2	22.9	9.9	28.2	4.4	39.6	6.0
Pervious LDI (pur_LDI)	11.2	2.3	0.0	23.5	4.3	43.1	30.4	79.6	5.8	53.2	6.1
Pervious MDI (pur_MDI)	0.1	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0	0.3	0.0
Pervious HDI (pur_HDI)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Impervious LDI (imp_LDI)	1.1	0.4	0.0	0.4	0.0	3.0	0.1	0.8	0.6	6.3	0.0
Impervious MDI (imp_MDI)	0.6	0.3	0.0	0.0	0.0	1.4	0.0	0.6	0.7	2.2	0.0
Impervious HDI (imp_HDI)	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Channel Erosion	0.6	0.8	0.0	0.0	0.0	1.2	1.0	21.5	1.3	29.2	0.0
Point Sources											
Existing Sediment Load	**434.8**	**65.8**	**17.3**	**269.1**	**39.8**	**1,081.1**	**169.3**	**999.8**	**307.8**	**1,120.4**	**54.8**
All-Forested Sediment Load	**65.2**	**24.6**	**15.5**	**116.2**	**19.3**	**40.8**	**69.3**	**325.1**	**13.8**	**505.2**	**36.0**
AllForX	**6.7**	**2.7**	**1.1**	**2.3**	**2.1**	**26.5**	**2.4**	**3.1**	**22.2**	**2.2**	**1.5**

Table C-3. Simulated Sediment Loads for Existing Conditions in Long Meadow Run and Turley Creek Watersheds

2007 BMP Scenario

Land Use/Source Categories	LOM1 Lower Long Meadow Run	LOM2 Upper Long Meadow Run	LOM3 Unnamed Tributary	LOM1x Long Meadow Run Total	TRL1 Lower Turley Creek	TRL2 Upper Turley Creek	TRL3 Brock Creek	TRL1x Turley Creek Total
	TMDL Watersheds — Sediment Load (tons/yr)							
HiTill Rowcrop (hit)	20.0	309.2	115.6	**444.8**	46.5	45.4	7.9	**99.8**
LoTill Rowcrop (lot)	12.6	195.3	71.8	**279.7**	29.5	28.4	5.0	**62.9**
Pasture (pas_g)	1.6	24.1	7.1	**32.8**	2.9	3.7	4.4	**11.0**
Pasture (pas_f)	49.8	816.0	260.0	**1,125.8**	102.8	137.2	146.9	**386.9**
Pasture (pas_p)	41.5	728.1	231.7	**1,001.3**	91.0	122.7	122.8	**336.4**
Riparian pasture (trp)	15.5	272.7	86.8	**375.1**	34.0	46.0	45.9	**125.9**
AFO (afo)	2.1	37.4	12.0	**51.5**	4.7	6.3	6.2	**17.2**
Hay (hay)	9.3	155.0	49.4	**213.7**	19.5	26.1	27.9	**73.5**
Forest (for)	0.1	12.4	3.3	**15.9**	6.8	5.6	56.3	**68.6**
Harvested forest (hvf)	0.0	1.2	0.3	**1.5**	0.6	0.5	4.9	**6.1**
Transitional (barren)	0.9	20.5	7.3	**28.7**	2.3	4.1	4.1	**10.4**
Pervious LDI (pur_LDI)	1.4	30.7	11.0	**43.1**	2.9	6.0	11.5	**20.4**
Pervious MDI (pur_MDI)	0.0	0.3	0.1	**0.4**	0.0	0.0	0.1	**0.1**
Pervious HDI (pur_HDI)	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Impervious LDI (imp_LDI)	0.2	3.5	1.0	**4.6**	0.3	0.2	1.2	**1.7**
Impervious MDI (imp_MDI)	0.2	2.5	0.5	**3.1**	0.0	0.1	0.6	**0.8**
Impervious HDI (imp_HDI)	0.0	0.3	0.0	**0.3**	0.0	0.0	0.5	**0.5**
Channel Erosion	1.4	0.1	0.3	**1.8**	1.8	0.3	0.7	**2.8**
Point Sources	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	**0.0**
Total Existing Sediment Load	156.6	2,609.3	858.2	**3,624.1**	345.6	432.7	446.8	**1,225.1**

Table C-4. Simulated Nitrogen Loads for Existing Conditions in Long Meadow Run Watershed

2007 BMP Scenario

Land Use/Source Categories	LOM1 **Lower Long Meadow Run**	LOM2 **Upper Long Meadow Run**	LOM3 **Unnamed Tributary**	**LOM1x** **Long Meadow Run Total**
	Nitrogen Load (lbs/yr)			
HiTill Rowcrop (hit)	58.6	627.6	239.9	**926.0**
LoTill Rowcrop (lot)	181.2	1,858.1	683.1	**2,722.4**
Pasture (pas_g)	28.7	280.4	75.7	**384.8**
Pasture (pas_f)	468.2	5,231.9	1,468.6	**7,168.7**
Pasture (pas_p)	314.0	3,878.4	1,111.2	**5,303.6**
Riparian pasture (trp)	64.5	859.3	279.9	**1,203.6**
AFO (afo)	73.9	1,106.3	315.2	**1,495.5**
Hay (hay)	61.2	701.3	199.8	**962.4**
Forest (for)	0.2	32.7	7.1	**40.0**
Harvested forest (hvf)	0.0	2.7	0.6	**3.3**
Transitional (barren)	0.9	16.1	6.3	**23.3**
Pervious LDI (pur_LDI)	18.4	288.3	89.4	**396.0**
Pervious MDI (pur_MDI)	0.4	4.1	0.8	**5.3**
Pervious HDI (pur_HDI)	0.0	0.1	0.0	**0.1**
Impervious LDI (imp_LDI)	15.0	312.7	87.8	**415.5**
Impervious MDI (imp_MDI)	31.0	446.7	81.9	**559.5**
Impervious HDI (imp_HDI)	0.0	45.4	0.0	**45.4**
Septic Systems	347.4	2,442.4	4,506.6	**7,296.5**
Channel Erosion	3.0	0.3	0.6	**3.9**
Groundwater	4,943.5	9,725.1	5,488.5	**20,157.1**
Total Nitrogen Load	6,610.0	27,859.8	14,643.1	**49,112.9**

Appendix D: GWLF Model Parameter Descriptions

D.1. Hydrology Parameters

Watershed-Related Parameter Descriptions

- Unsaturated Soil Moisture Capacity (SMC, cm): The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- Recession coefficient (day^{-1}): The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. This parameter was evaluated using the following relationship from Lee et al. (2000): RecCoeff = 0.045 + 1.13/(0.306 + Area in square kilometers)
- Seepage coefficient: The seepage coefficient represents the fraction of flow lost as seepage to deep storage. As part of the nitrogen calibration process, this value was set to 0.80 for Long Meadow Run, and 0.05 for all others.
- Leakage coefficient: The leakage coefficient represents the fraction of infiltration that bypasses the unsaturated zone through macro-pore flow. An increase in this coefficient decreases ET losses and increases baseflow. These values were set to zero.

The following parameters were initialized by running the model for a 9-month period prior to the period used for load calculation:

- Initial unsaturated storage (cm): Initial depth of water stored in the unsaturated (surface) zone.
- Initial saturated storage (cm): Initial depth of water stored in the saturated zone.
- Initial snow (cm): Initial amount of snow on the ground at the beginning of the simulation.
- Antecedent Rainfall for each of 5 previous days (cm): The amount of rainfall on each of the five days preceeding the current day.

Month-Related Parameter Descriptions

- Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model.
- ET_CV: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- Hours per Day: Mean number of daylight hours.

- Erosion Coefficient: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.

Land Use-Related Parameter Descriptions

- Curve Number: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance (USDA-SCS, 1986).

D.2. Sediment Parameters

Watershed-Related Parameter Descriptions

- Sediment delivery ratio: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- USLE K-factor: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- USLE LS-factor: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- USLE C-factor: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997); and then adjusted after consultation with local NRCS personnel.
- Daily sediment buildup rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans et al., 2003)

- % Developed land: percentage of the watershed with urban-related land uses – defined as all land in MDI and HDI land uses, as well as the impervious portions of LDI.
- Animal density: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- Curve Number: area-weighted average value for the watershed.
- K Factor: area-weighted USLE soil erodibility factor for the watershed.
- Slope: mean percent slope for the watershed.
- Stream length: calculated as the total stream length of natural perennial stream channels, in meters.

- Mean channel depth (m): calculated from relationships developed either by the Chesapeake Bay Program or by USDA-NRCS by physiographic region, of the general form: $y = a * A^b$, where y = mean channel depth in ft, A = drainage area in square miles, and "a" and "b" are regression coefficients (USDA-NRCS, 2005). The mean channel depth was then converted from feet to meters.

D.3. Nitrogen Parameters

Watershed-Related Parameter Descriptions

- Sediment N and P (mg/kg): Soil-phase nutrients in sediment are estimated as sediment N and P. Sediment N and P are calculated for each nutrient as the soil N or P content multiplied by an N or P enrichment ratio. Sediment N was used as a calibration parameter.
- Groundwater N and P (mg/L): Mean concentrations of N and P in groundwater discharge. Groundwater N was used as a calibration parameter.
- No. of Rural (Pervious) Land Uses Receiving Manure Applications: The number of non-pasture rural land uses simulated as receiving applications of spread manure.

- Beg and End Months for Each of Two Manure Application Periods: A basic assumption in the model revision by Penn State is that there are Spring and Fall periods during which manure may be applied to the land. Each period is defined by a beginning and an ending month.

Landuse-Related Parameter Descriptions

- Dissolved Nutrient Concentrations in Runoff (N, P) By Land Use (mg/L): These concentrations correspond to runoff from the respective landuses during periods without manure applications
- Impervious Area Build-up Rates By Land Use: Sed (kg/ha-d), N and P (kg/kg Sed): These are the daily rates of pollutant build-up on the surface, on days without rainfall.
- Runoff N and P from Areas receiving Manure Applications (mg/L): These are landuse-specific concentrations of N and P that correspond to periods of manure application.

Month-Related Parameter Descriptions

- Monthly Point Source Loads (N, P): Monthly loads of N and P from point sources can be entered with these parameters in units of kg/month. No point source loads were included in this assessment.

- Septic System Flag: This flag should be set to "1" if septic systems are to be simulated, and "0" if they are not. When set to "1", the following three types of data are expected:
  - Septic System Monthly Population Distribution: This matrix of numbers represents the population distribution by month of persons in each of the four types of septic system categories – normal, ponded, short-circuited, and direct discharge systems as defined in the GWLF Manual (Haith et al., 1992).
    - Normal system: a system whose construction, operation, and maintenance conform to recommended procedures and regulations.
    - Ponded system: a system that exhibits hydraulic failure of the tank's absorption field resulting in the surfacing of the effluent.
    - Short-circuited system: a system located so close (< 15m) to surface waters that negligible adsorption of phosphorus takes place. This category is not evaluated in this assessment.
    - Direct-discharge system: a septic tank or straight pipe that transfers its effluent directly into surface waters.
  - Septic System Effluent N and P (g/person-day): These values represent mean daily nutrient loads in the septic system effluent.
  - Plant Nutrient Uptake N and P (g/day): The monthly rates of N and P uptake by plants are each specified by two values – one for months during the growing season, and one for months during the dormant season.

Appendix E: GWLF Model Parameter Values

The GWLF parameter values used for the Long Meadow Run and Turley Creek watershed simulations are shown in Table E-1 through Table E-3. Table E-1 lists the various watershed-wide parameters and their values, Table E-2 displays the monthly variable evapo-transpiration cover coefficients, and Tables E-3 and E-4 show the land use-related parameters – runoff curve numbers (CN) and the Universal Soil Loss Equation's KLSCP product - used for erosion modeling, for Long Meadow Run and Turley Creek, respectively. Calibrated parameters and their calibrated values are indicated in each of the tables. Corresponding GWLF parameter values for the comparison watersheds are shown in Tables E-5 through E-7. Since the modeling was performed in metric units, note that all of the input parameters are in metric units, even though the simulated results shown in this report are presented in English units.

Table E-1. GWLF Watershed Parameters for Long Meadow Run and Turley Creek Watersheds

GWLF Watershed Parameters	units	TMDL Watersheds							
		LOM1	LOM2	LOM3	LOM1x	TRL1	TRL2	TRL3	TRL1x
recession coefficient	(day^{-1})	0.5517	0.0835	0.1655	0.0730	0.2965	0.2279	0.1224	0.0908
seepage coefficient		0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000	0.8000
leakage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sediment delivery ratio		0.1953	0.1953	0.1953	0.1953	0.1953	0.1953	0.1953	0.1953
unsaturated water capacity	(cm)	16.98	16.98	16.98	16.98	16.98	16.98	16.98	16.98
erosivity coefficient (Nov - Apr)		0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
erosivity coefficient (growing season)		0.404	0.404	0.404	0.404	0.404	0.404	0.404	0.404
% developed land	(%)	0.47	0.48	0.42	0.46	0.19	0.16	0.33	0.23
no. of livestock	(AU)	53	660	215	928	72	116	99	287
area-weighted runoff curve number		75.70	70.07	70.20	70.38	68.04	68.48	66.39	67.07
area-weighted soil erodibility		0.297	0.316	0.334	0.319	0.287	0.284	0.260	0.270
area-weighted slope	(%)	6.83	9.43	9.05	9.22	13.96	10.60	19.48	16.39
aFactor		0.0000719	0.0000740	0.0000811	0.0000756	0.0000565	0.0000534	0.0000451	0.0000484
total stream length	(m)	2,613.5	587.7	3,009.8	6,211.0	3,279.8	3,677.9	3,998.3	10,956.1
Mean Channel Depth	(m)	0.435	0.984	0.693	1.084	0.549	0.608	0.795	0.933
Groundwater N concentration	(mg/L)	7.953	4.967	4.967	4.967				
Sediment N content	(mg/kg sed)	2100	2100	2100	2100				

Table E-2. GWLF Monthly ET Cover Coefficients – Long Meadow Run and Turley Creek Watersheds

Watershed	ID	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Lower Long Meadow Run	LOM1	0.976	0.981	0.983	**0.983**	0.965	0.947	0.928	0.891	0.873	**0.861**	0.922	0.964
Upper Long Meadow Run	LOM2	0.978	0.983	0.985	**0.985**	0.966	0.947	0.928	0.890	0.870	**0.858**	0.921	0.965
Unnamed Tributary	LOM3	0.977	0.983	0.985	**0.985**	0.966	0.947	0.928	0.890	0.871	**0.858**	0.921	0.965
LowerTurley Creek	TRL1	0.981	0.988	0.990	**0.990**	0.967	0.945	0.922	0.877	0.854	**0.839**	0.915	0.966
Upper Turley Creek	TRL2	0.981	0.987	0.989	**0.989**	0.969	0.949	0.929	0.889	0.869	**0.856**	0.923	0.968
Brock Creek	TRL3	0.984	0.991	0.994	**0.994**	0.969	0.944	0.919	0.869	0.844	**0.827**	0.910	0.967
Cumulative Long Meadow Run	LOM1x	0.977	0.983	0.985	**0.985**	0.966	0.947	0.928	0.890	0.871	**0.858**	0.921	0.965
Cumulative Turley Creek	TRL1x	0.983	0.990	0.992	**0.992**	0.969	0.946	0.922	0.876	0.852	**0.837**	0.914	0.967

* July values represent the maximum composite ET coefficients during the growing season.
** Jan values represent the minimum composite ET coefficients during the dormant season.

Table E-3. GWLF Land Use Parameters – Long Meadow Run Watershed

Landuse	Lower Long Meadow Run (LOM1)		Upper Long Meadow Run (LOM2)		Unnamed Tributary (LOM3)		Long Meadow Run (LOM1x)	
	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.2692	82.4	0.4135	79.7	0.4230	79.3	0.4056	79.7
LoTill Rowcrop (lot)	0.0654	80.4	0.1004	77.7	0.1028	77.4	0.0985	77.8
Pasture (pas_g)	0.0187	66.8	0.0274	61.8	0.0269	61.1	0.0268	61.9
Pasture (pas_f)	0.0750	73.5	0.1097	69.6	0.1078	69.1	0.1071	69.7
Pasture (pas_p)	0.1331	82.1	0.1947	79.4	0.1913	79.1	0.1901	79.5
Riparian pasture (trp)	1.1459	82.1	1.6762	79.4	1.6482	79.1	1.6374	79.5
AFO (afo)	0.0000	91.0	0.7238	91.0	0.7113	91.0	0.7068	91.0
Hay (hay)	0.0506	73.2	0.0740	69.6	0.0727	69.1	0.0723	69.7
Forest (for)	0.0048	65.7	0.0045	60.8	0.0054	60.1	0.0047	60.9
Harvested forest (hvf)	0.0484	71.0	0.0453	66.7	0.0538	66.1	0.0468	66.8
Transitional (barren)	1.0251	88.3	1.3069	86.3	1.3109	86.1	1.2861	86.4
Pervious LDI (pur_LDI)	0.0179	73.5	0.0247	69.6	0.0245	69.1	0.0243	69.7
Pervious MDI (pur_MDI)	0.0108	73.5	0.0181	69.6	0.0236	69.1	0.0188	69.7
Pervious HDI (pur_HDI)	0.0198	73.5	0.0118	69.6	0.0223	69.1	0.0118	69.7
Impervious LDI (imp_LDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Table E-4. GWLF Land Use Parameters – Turley Creek Watershed

Landuse	LowerTurley Creek (TRL1)		Upper Turley Creek (TRL2)		Brock Creek (TRL3)		Cumulative Turley Creek (TRL1x)	
	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.4243	79.7	0.3366	79.5	0.3050	81.6	0.3817	80.7
LoTill Rowcrop (lot)	0.1031	77.8	0.0818	77.5	0.0741	79.5	0.0927	78.7
Pasture (pas_g)	0.0283	61.9	0.0236	61.4	0.0272	65.0	0.0261	63.6
Pasture (pas_f)	0.1132	69.7	0.0945	69.3	0.1090	72.0	0.1044	71.0
Pasture (pas_p)	0.2009	79.5	0.1677	79.2	0.1935	81.1	0.1853	80.4
Riparian pasture (trp)	1.7264	79.5	1.4452	79.2	1.6614	81.1	1.5950	80.4
AFO (afo)	0.0000	91.0	0.6236	91.0	0.7194	91.0	0.6892	91.0
Hay (hay)	0.0764	69.7	0.0638	69.3	0.0736	72.0	0.0705	71.0
Forest (for)	0.0076	60.9	0.0058	60.4	0.0079	63.9	0.0076	62.5
Harvested forest (hvf)	0.0758	66.8	0.0583	66.4	0.0791	69.5	0.0765	68.3
Transitional (barren)	1.3015	86.4	1.1186	86.2	0.7116	87.7	0.7888	87.1
Pervious LDI (pur_LDI)	0.0203	69.7	0.0196	69.3	0.0238	72.0	0.0220	71.0
Pervious MDI (pur_MDI)	0.0153	69.7	0.0146	69.3	0.0154	72.0	0.0160	71.0
Pervious HDI (pur_HDI)	0.0169	69.7	0.0168	69.3	0.0116	72.0	0.0116	71.0
Impervious LDI (imp_LDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Table E-5. GWLF Watershed Parameters for Comparison Watersheds

GWLF Watershed Parameters	units	AllForX Comparison Watersheds									
		BVR	CDR	CUB	LAR	LEW	LSC	MFT	MIL	NAK	NTH
recession coefficient	(day^{-1})	0.0960	0.1329	0.0735	0.1308	0.1539	0.0785	0.0685	0.0775	0.0550	0.0704
seepage coefficient		0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500	0.0500
leakage coefficient		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
sediment delivery ratio		0.1698	0.1812	0.1507	0.1808	0.1844	0.1568	0.1425	0.1556	0.1105	0.1458
unsaturated water capacity	(cm)	10.81	11.12	12.92	13.96	22.87	16.90	19.42	23.23	25.49	20.92
erosivity coefficient (Nov - Apr)		0.144	0.098	0.149	0.191	0.119	0.191	0.119	0.149	0.083	0.098
erosivity coefficient (growing season)		0.248	0.207	0.404	0.228	0.225	0.228	0.225	0.404	0.176	0.174
% developed land	(%)	0.12	0.00	0.03	0.00	1.04	0.01	0.06	0.11	0.19	0.00
no. of livestock	(AU)	29	1	40	4	218	38	126	425	369	4
area-weighted runoff curve number		70.15	53.42	52.11	61.18	69.44	63.97	66.89	62.10	60.94	39.97
area-weighted soil erodibility		0.268	0.122	0.139	0.126	0.308	0.186	0.292	0.218	0.235	0.102
area-weighted slope	(%)	22.73	23.98	25.85	25.56	11.05	24.02	24.39	16.08	24.21	32.24
aFactor		0.0000494	0.0000001	0.0000001	0.0000001	0.0000792	0.0000078	0.0000580	0.0000197	0.0000299	0.0000001
total stream length	(m)	6,545.5	3,690.0	21,867.0	5,670.0	6,100.2	21,661.7	35,513.0	17,136.2	51,256.6	29,869.1
Mean Channel Depth	(m)	0.903	0.765	1.078	0.770	0.716	1.027	1.144	1.037	1.480	1.117
Groundwater N concentration	(mg/L)	0.441	0.441	1.749	0.441	3.903	0.441	1.910	0.789	1.910	0.441
Sediment N content	(mg/kg sed)	4500	2100	2100	2100	2100	2100	2100	2100	2100	4500

Table E-6. GWLF Monthly ET Cover Coefficients – Comparison Watersheds

Watershed	ID	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan**	Feb	Mar
Beaver Creek	BVR	0.987	0.995	0.998	**0.998**	0.970	0.941	0.912	0.855	0.826	**0.807**	0.902	0.968
Cedar Creek	CDR	0.988	0.997	1.000	**1.000**	0.970	0.940	0.910	0.850	0.820	**0.800**	0.900	0.968
Cub Run	CUB	0.988	0.996	0.999	**0.999**	0.970	0.942	0.913	0.856	0.827	**0.808**	0.904	0.968
Laurel Run	LAR	0.988	0.997	1.000	**1.000**	0.971	0.942	0.913	0.856	0.827	**0.808**	0.904	0.969
Lewis Creek	LEW	0.975	0.980	0.981	**0.981**	0.966	0.950	0.934	0.903	0.888	**0.877**	0.929	0.965
Little Stony Creek	LSC	0.988	0.996	0.999	**0.999**	0.971	0.943	0.915	0.859	0.831	**0.812**	0.906	0.969
Moffett Creek	MFT	0.987	0.995	0.998	**0.998**	0.971	0.944	0.917	0.863	0.836	**0.818**	0.908	0.969
Mill Creek	MIL	0.984	0.991	0.993	**0.993**	0.970	0.946	0.922	0.875	0.852	**0.836**	0.915	0.968
Naked Creek	NAK	0.986	0.994	0.996	**0.996**	0.969	0.942	0.915	0.861	0.834	**0.816**	0.906	0.968
North River	NTH	0.988	0.997	1.000	**1.000**	0.971	0.942	0.912	0.854	0.825	**0.806**	0.903	0.969

* July values represent the maximum composite ET coefficients during the growing season.
** Jan values represent the minimum composite ET coefficients during the dormant season.

Table E-7. GWLF Land Use Parameters - Comparison Watersheds

Landuse	Beaver Creek (BVR)		Cedar Creek (CDR)		Cub Run (CUB)		Laurel Run (LAR)		Lewis Creek (LEW)	
	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN	KLSCP	CN
HiTill Rowcrop (hit)	0.2541	84.7	0.1333	77.0	0.1596	76.1	0.1486	80.2	0.4525	79.6
LoTill Rowcrop (lot)	0.0617	82.6	0.0324	75.0	0.0388	74.1	0.0361	78.2	0.1099	77.7
Pasture (pas_g)	0.0292	70.6	0.0103	55.2	0.0155	53.3	0.0410	62.1	0.0299	61.8
Pasture (pas_f)	0.1168	76.4	0.0410	63.2	0.0620	61.5	0.1641	69.3	0.1195	69.6
Pasture (pas_p)	0.2073	84.1	0.0728	76.3	0.1100	75.3	0.2913	79.7	0.2120	79.4
Riparian pasture (trp)	1.7809	84.1	0.6272	76.3	0.9482	75.3	2.2631	79.7	1.8212	79.4
AFO (afo)	0.7707	91.0	0.2708	91.0	0.4091	91.0	1.0830	91.0	0.7884	91.0
Hay (hay)	0.0788	76.2	0.0277	65.6	0.0418	64.5	0.1108	70.0	0.0806	69.5
Forest (for)	0.0088	69.5	0.0040	53.3	0.0048	51.2	0.0044	60.7	0.0054	60.8
Harvested forest (hvf)	0.0876	74.5	0.0401	60.1	0.0476	58.4	0.0437	66.5	0.0544	66.7
Transitional (barren)	1.0617	90.1	0.5736	83.5	0.6690	82.9	0.6557	86.3	1.6193	86.3
Pervious LDI (pur_LDI)	0.0214	76.4	0.0133	63.2	0.0236	61.5	0.0167	69.3	0.0365	69.6
Pervious MDI (pur_MDI)	0.0085	76.4	0.0101	63.2	0.0124	61.5	0.0112	69.3	0.0338	69.6
Pervious HDI (pur_HDI)	0.0174	76.4	0.0083	63.2	0.0103	61.5	0.0093	69.3	0.0075	69.6
Impervious LDI (imp_LDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Landuse	**Little Stony Creek (LSC)**		**Moffett Creek (MFT)**		**Mill Creek (MIL)**		**Naked Creek (NAK)**		**North River (NTH)**	
	KLSCP	**CN**	**KLSCP**	**CN**	**KLSCP**	**CN**	**KLSCP**	**CN**	**KLSCP**	**CN**
HiTill Rowcrop (hit)	0.1158	81.6	0.4207	82.8	0.2957	78.0	0.1113	79.4	0.1531	70.7
LoTill Rowcrop (lot)	0.0281	79.6	0.1022	80.7	0.0718	76.0	0.0270	77.4	0.0372	68.8
Pasture (pas_g)	0.0196	64.6	0.0339	66.9	0.0250	58.0	0.0091	60.6	0.0098	42.3
Pasture (pas_f)	0.0782	71.2	0.1355	73.3	0.1000	66.0	0.0365	68.1	0.0391	51.9
Pasture (pas_p)	0.1388	81.1	0.2405	82.2	0.1776	77.5	0.0647	78.9	0.0695	69.7
Riparian pasture (trp)	1.1960	81.1	2.0507	82.2	1.5284	77.5	0.5532	78.9	0.5869	69.7
AFO (afo)	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0	0.0000	91.0
Hay (hay)	0.0528	71.9	0.0915	73.6	0.0675	67.2	0.0246	69.0	0.0264	57.1
Forest (for)	0.0060	63.2	0.0102	65.7	0.0048	56.5	0.0088	59.2	0.0040	39.5
Harvested forest (hvf)	0.0603	68.8	0.1016	71.1	0.0484	63.0	0.0879	65.2	0.0404	48.1
Transitional (barren)	1.0018	87.4	1.3308	88.5	0.9144	84.8	0.9302	85.8	0.6409	78.3
Pervious LDI (pur_LDI)	0.0379	71.2	0.0394	73.3	0.0317	66.0	0.0144	68.1	0.0121	51.9
Pervious MDI (pur_MDI)	0.0155	71.2	0.0172	73.3	0.0122	66.0	0.0217	68.1	0.0116	51.9
Pervious HDI (pur_HDI)	0.0128	71.2	0.0208	73.3	0.0124	66.0	0.0208	68.1	0.0096	51.9
Impervious LDI (imp_LDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious MDI (imp_MDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0
Impervious HDI (imp_HDI)	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0	0.0000	98.0

LDI = low intensity developed; MDI = medium intensity developed; HDI = high intensity developed

Appendix F: Setting TMDL Endpoints and MOS using the AllForX Approach

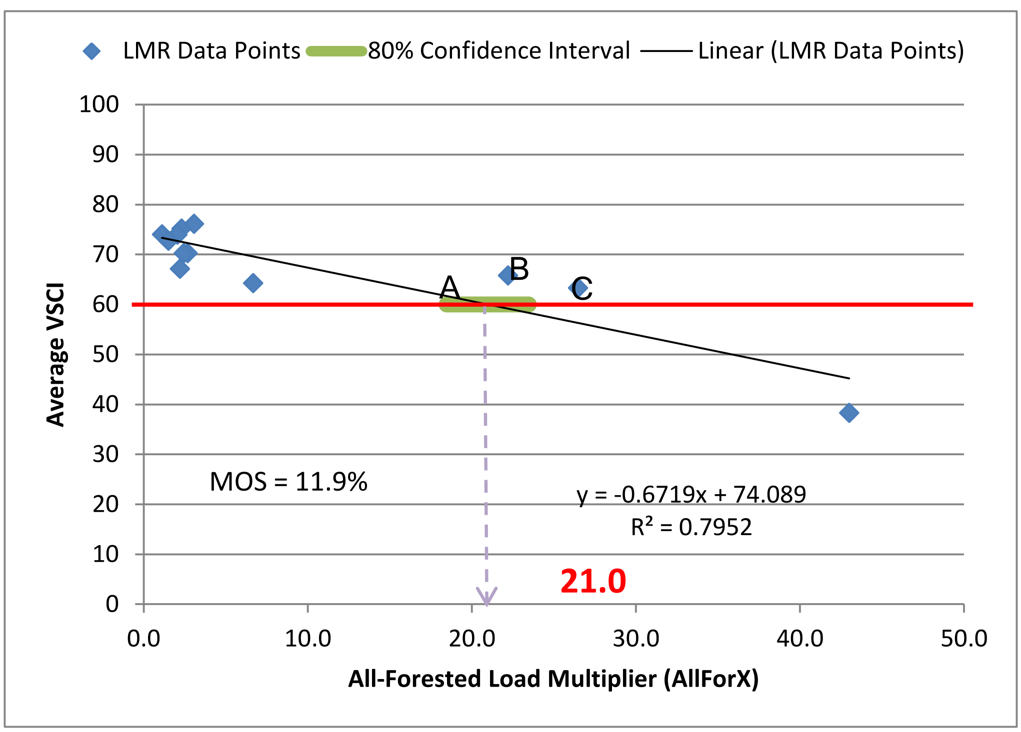
In the AllForX approach, introduced in Chapter 4, the metric used for setting a numeric pollutant threshold is the All-Forest Load Multiplier (AllForX), calculated as the existing sediment load normalized by the corresponding load under an all-forest condition. AllForX is calculated as the existing pollutant load in any given watershed divided by the corresponding pollutant load simulated under an all-forest condition. When AllForX is regressed against VSCI for a number of healthy watersheds surrounding a particular TMDL watershed or set of TMDL watersheds, the developed relationship can be used to quantify the value of the AllForX threshold that corresponds to the biological health threshold (VSCI < 60) used to assess aquatic life use impairments in Virginia. The pollutant TMDL load is then calculated as the value of the AllForX threshold times the all-forest pollutant load of the TMDL watershed. Since a number of watersheds are used to quantify the regression, a confidence interval around the threshold was used to quantify the margin of safety in the Total Maximum Daily Load equation. AllForX regressions were created to identify sediment AllForX threshold values for both Long Meadow Run and Turley Creek and a nitrogen AllForX threshold value for Long Meadow Run.

<u>Sediment Thresholds</u>

Existing sediment loads were calculated for both impaired TMDL watersheds in this study and for each of eleven (11) comparison watersheds. A second model run, substituted forest land use-related parameters for each of the other land uses, while preserving the unique characteristics of soil and slope distributions across each watershed. A value of AllForX was then calculated for each watershed by dividing their existing sediment or nitrogen load by their all-forest load. The modeling results for each watershed were summarized as long-term averages for each watershed, previously shown in Tables C-1 and C-2, along with average values for the Virginia Stream Condition Index (VSCI).

After performing load calculations, separate regression equations were determined for Long Meadow Run and Turley Creek for sediment, and for Long Meadow Run for nitrogen.

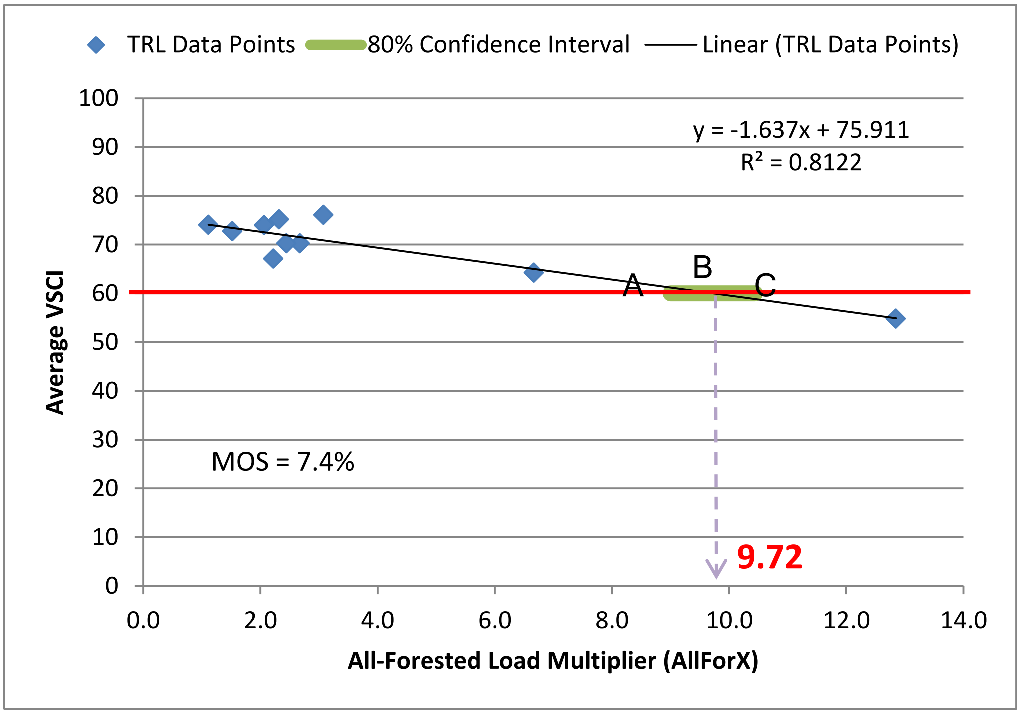
The regression developed between AllForX and VSCI for Long Meadow Run and the comparison watersheds for sediment is shown in Figure F-1. The value of AllForX used to set the sediment TMDL load (the AllForX threshold) was the value where the regression line crossed the biological impairment threshold of VSCI = 60 (AllForX = 21.0), indicated by point B. The TMDL load for each watershed was then calculated as its All-Forest sediment load times the AllForX threshold (21.0). An 80% confidence interval was then calculated around the point where the regression line intersects the biological impairment threshold (VSCI = 60). The margin of safety (MOS) was calculated as the All-Forest sediment load times the difference in AllForX between the point where the regression crosses VSCI = 60 (AllForX = 21.0) and the lower bound of the 80% confidence interval (AllForX = 18.46), amounting to 11.9%. Note that the MOS is equal to this difference expressed as a percentage of the AllForX threshold, and therefore is the same for all watersheds using this regression.



B = AllForX endpoint value used for the TMDL; AC = the 80% Confidence Interval (shown in green); (B - A)/B = The MOS fraction; A = AllForX value used for the target allocation load.

Figure F-1. Regression and AllForX Threshold for Sediment in Long Meadow Run

In a similar fashion, the sediment regression developed between AllForX and VSCI for Turley Creek and comparison watersheds is shown in Figure F-1. The value of AllForX used to set the sediment TMDL load (the AllForX threshold) was the value where the regression line crossed the biological impairment threshold of VSCI = 60 (AllForX = 9.72), indicated by point B. The TMDL load for each watershed was then calculated as its All-Forest sediment load times the AllForX threshold (9.72). An 80% confidence interval was then calculated around the point where the regression line intersects the biological impairment threshold (VSCI = 60). The margin of safety (MOS) was calculated as the All-Forest sediment load times the difference in AllForX between the point where the regression crosses VSCI = 60 (AllForX = 9.72) and the lower bound of the 80% confidence interval (AllForX = 9.00). The MOS for Turley Creek was 7.4%.



B = AllForX endpoint value used for the TMDL; AC = the 80% Confidence Interval (shown in green); (B - A)/B = The MOS fraction; A = AllForX value used for the target allocation load.

Figure F-2. Regression and AllForX Threshold for Sediment in Turley Creek

Existing, TMDL, and MOS sediment loads are shown in Table for each TMDL watershed. Since the MOS is a measure of uncertainty in the TMDL, the implementation target load is the TMDL minus the MOS, and the percent reduction is calculated as the change from the future load to the allocation target load.

Table F-1. Calculation of the Sediment TMDL and MOS for both Watersheds

AllForX Calculation Components	Units	LOM1x Long Meadow Run Total	TRL1x Turley Creek Total
Total Existing Sediment Load	**tons/yr**	**3,624.1**	**1,225.1**
All-Forest Sediment Load	tons/yr	84.3	95.4
AllForX @ VSCI = 60		20.96	9.72
TMDL Sediment Load	**tons/yr**	**1,766.4**	**926.8**
AllForX @ LCL 80%CI		18.46	9.00
Margin of Safety (MOS)	**tons/yr**	**210.8**	**68.7**
Margin of Safety (%)		11.9%	7.4%
TMDL Reduction Endpoint (TMDL-MOS)	tons/yr	1,555.6	858.1
Existing Sediment Load		3,256.1	1,216.3
Overall Reduction from Existing Load	tons/yr	1,700.6	358.1
Overall %Reduction from Existing Load	%	52.2%	29.4%

The relationship between AllForX and the biological condition was further validated with the following plots and regressions between AllForX and various independent sediment-related habitat metrics for the impaired watersheds: average habitat sediment deposition in Figure F-; average epifaunal substrate in Figure F-; and embeddedness in Figure F-. The impaired watersheds are indicated by the red markers and the comparison watersheds in blue.

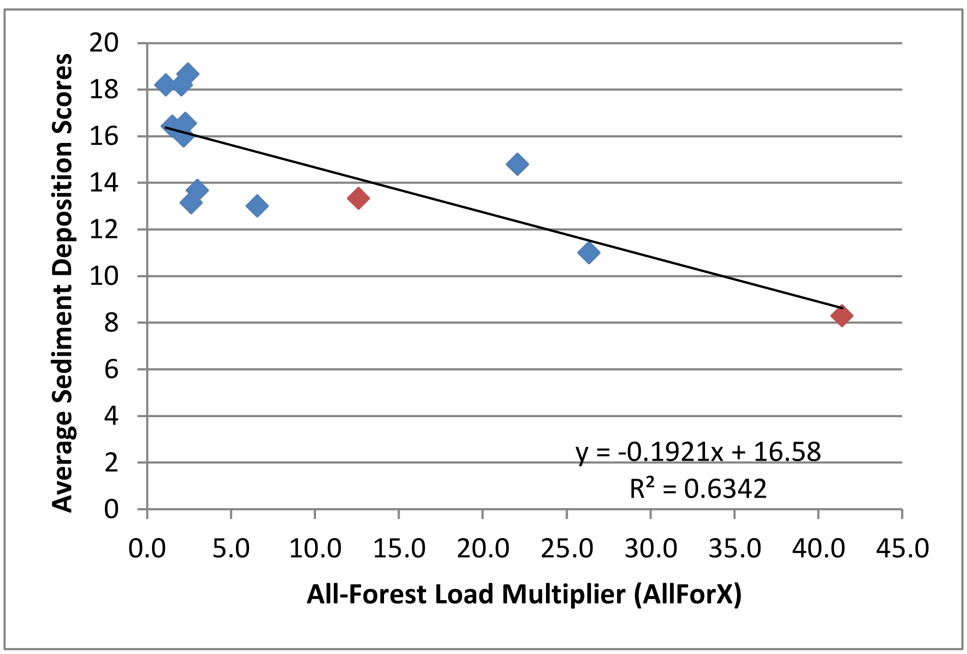


Figure F-3. Sediment AllForX vs. Average Habitat Sediment Deposition Scores

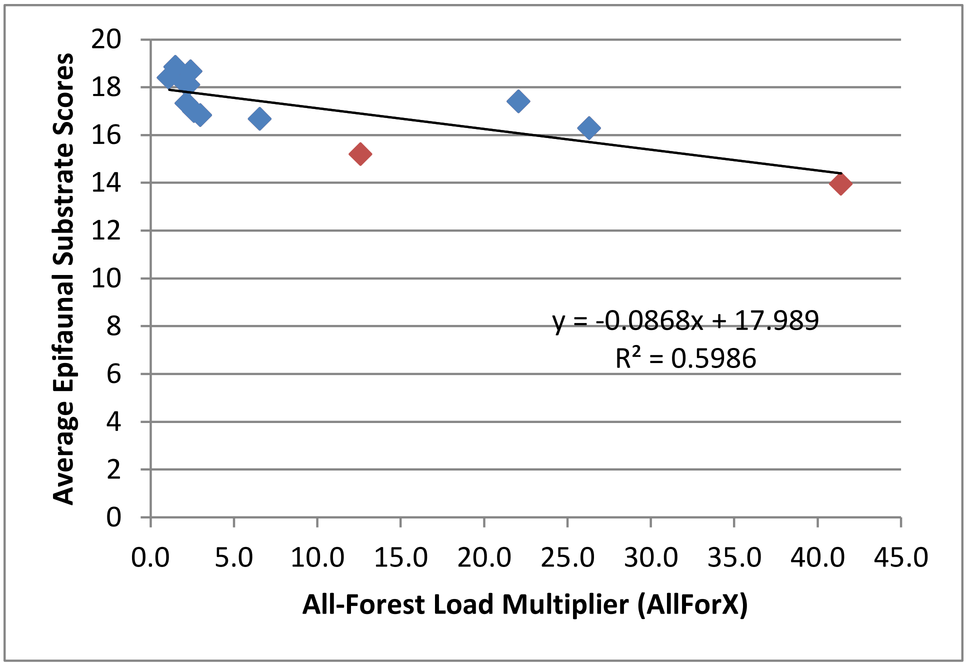


Figure F-4. Sediment AllForX vs. Average Habitat Epifaunal Substrate Scores

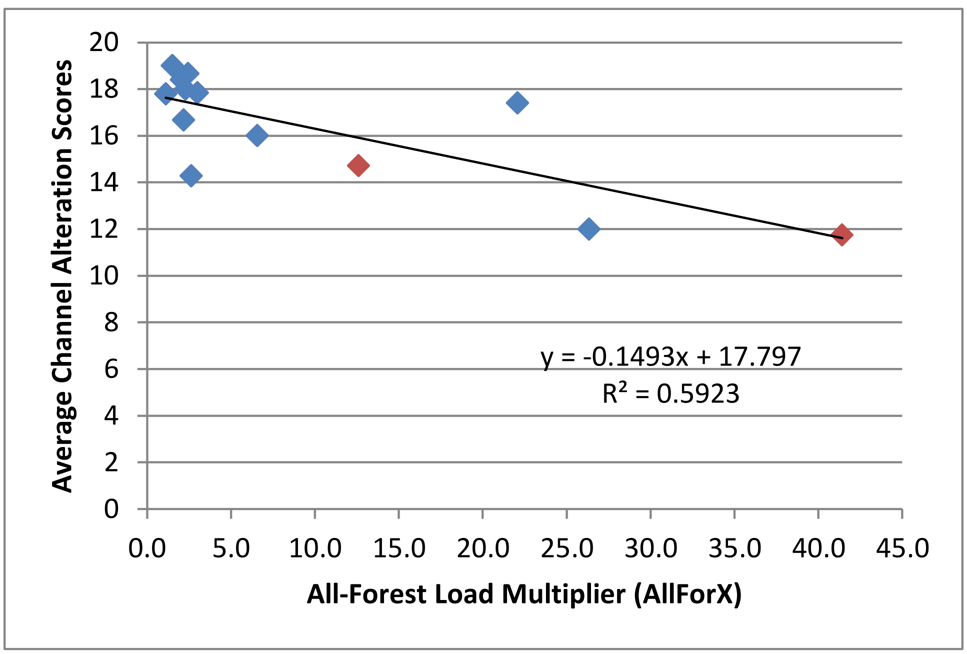
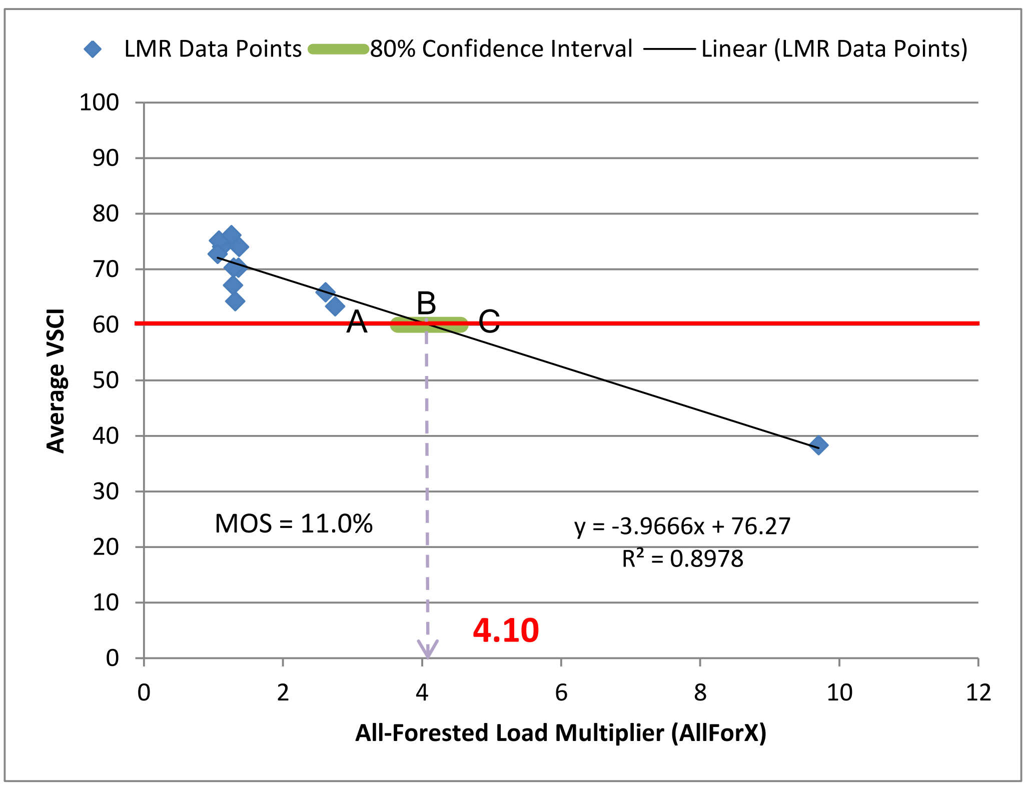


Figure F-5. Sediment AllForX vs. Average Channel Alteration Scores

Nitrogen Threshold

The nitrogen regression developed between AllForX and VSCI for Long Meadow Run and the comparison watersheds is shown in Figure F-1. The value of AllForX used to set the nitrogen TMDL load (the AllForX threshold) was the value where the regression line crossed the biological impairment threshold of VSCI = 60 (AllForX = 4.10), indicated by point B. The TMDL load for each watershed was then calculated as its All-Forest sediment load times the AllForX threshold (4.10). An 80% confidence interval was then calculated around the point where the regression line intersects the biological impairment threshold (VSCI = 60). The margin of safety (MOS) was calculated as the All-Forest sediment load times the difference in AllForX between the point where the regression crosses VSCI = 60 (AllForX = 4.10) and the lower bound of the 80% confidence interval (AllForX = 3.65), amounting to 11.0%. Note that the MOS is equal to this difference expressed as a percentage of the AllForX threshold, and therefore is the same for all watersheds using this regression.



B = AllForX endpoint value used for the TMDL; AC = the 80% Confidence Interval (shown in green); (B - A)/B = The MOS fraction; A = AllForX value used for the target allocation load.

Figure F-6. Regression and AllForX Threshold for Nitrogen in Long Meadow Run

Existing, TMDL, and MOS nitrogen loads are shown in Table for the Long Meadow Run watershed. Since the MOS is a measure of uncertainty in the TMDL, the implementation target load is the TMDL minus the MOS, and the percent reduction is calculated as the change from the future load to the allocation target load.

Table F-2. Calculation of the Nitrogen TMDL and MOS for Long Meadow Run

AllForX Calculation Components	Units	LOM1x Long Meadow Run Total
Total Nitrogen Load	**lbs/yr**	**49,112.9**
All-Forest Nitrogen Load	lbs/yr	4,761.9
AllForX @ VSCI = 60		4.10
TMDL Nitrogen Load	**lbs/yr**	**19,532.1**
AllForX @ LCL 80%CI		3.65
Margin of Safety (MOS)	**lbs/yr**	**2,144.8**
Margin of Safety (%)		11.0%
TMDL Reduction Endpoint (TMDL-MOS)	lbs/yr	17,387.4
Existing Nitrogen Load		47,660.5
Overall Reduction from Existing Load	lbs/yr	30,273.2
Overall %Reduction from Existing Load	%	63.5%

The relationship between AllForX and the biological condition was further validated with the following plots and regressions between nitrogen AllForX and various independent habitat metrics for the impaired watersheds: average habitat sediment deposition in Figure F-; average epifaunal substrate in Figure F-; and channel alteration in Figure F-. The impaired watersheds are indicated by the red markers and the comparison watersheds in blue.

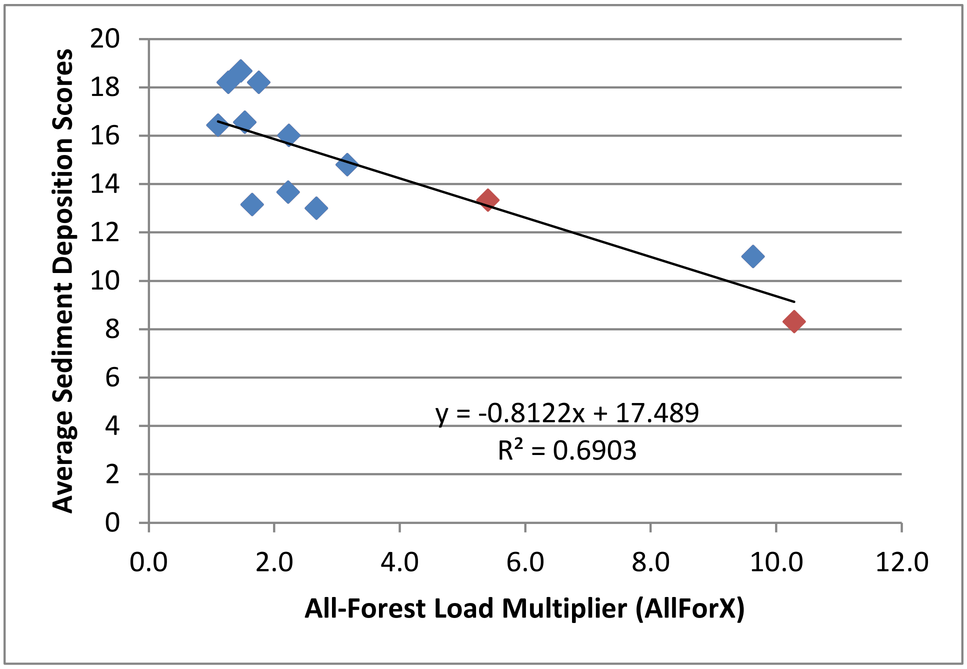


Figure F-7. Nitrogen AllForX vs. Average Habitat Sediment Deposition Scores

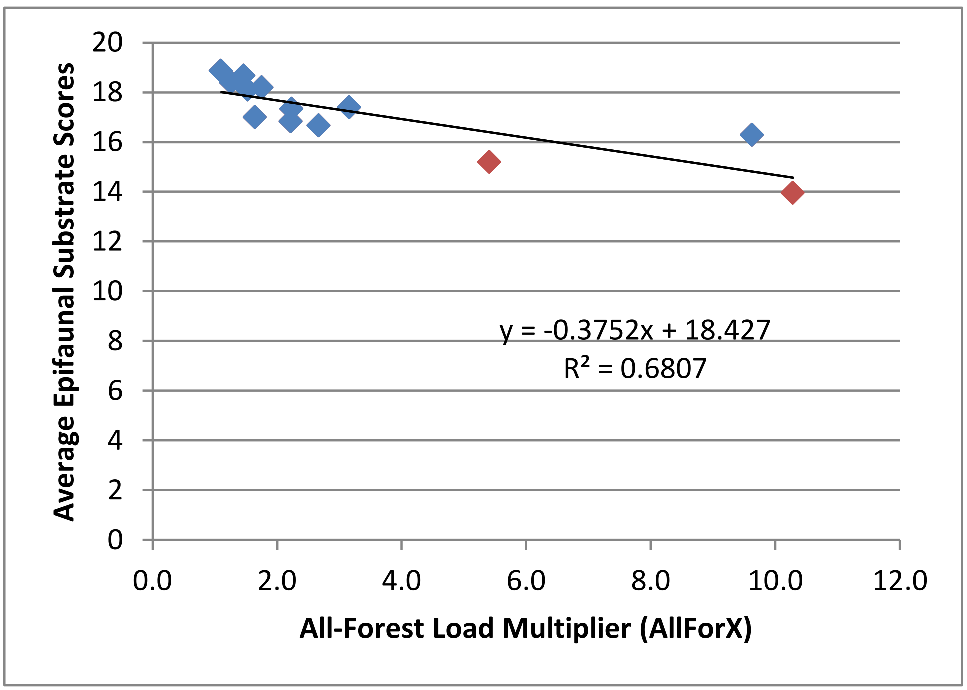


Figure F-8. Nitrogen AllForX vs. Average Habitat Epifaunal Substrate Scores

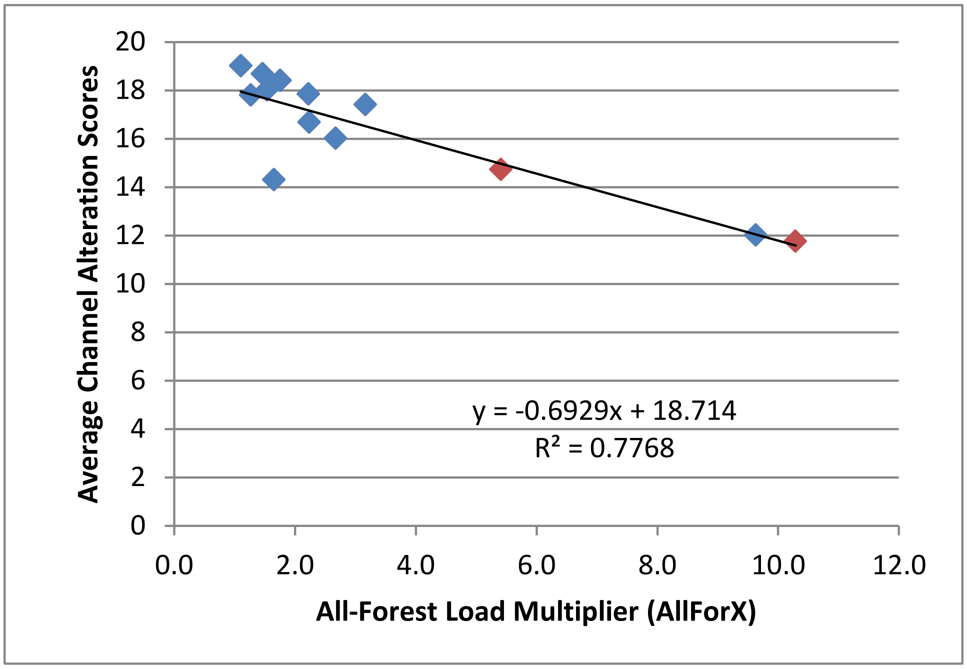


Figure F-9. Nitrogen AllForX vs. Average Channel Alteration Scores

Appendix G: Accounting for BMPs in Existing Loads

For the AllForX and the Existing conditions modeling, BMPs were simulated as passthru factors by state 6-digit HUC watersheds for both the impaired and comparison watersheds. These passthru factors accounted for BMPs installed from 2002 through 2007, and were the same ones used by Virginia DCR for the 2014 Statewide Watershed Nonpoint Source Pollutant Load Assessment.

For the 2009 baseline Existing Conditions modeling, active BMP extents were assessed and summarized from local SWCD and NRCS data that corresponded with additional BMPs installed between 2008 and 2009 to correspond with the simulated land use and weather. GIS spatial analyses were used to extract BMPs that fell within the Long Meadow Run and Turley Creek portions of state HUs PS57 and PS55, respectively. These were then spatially joined with appropriate sub-watersheds within Long Meadow Run and Turley Creek watersheds. Pivot tables were then created in an EXCEL spreadsheet to summarize BMP extents for each sub-watershed by practice and year installed. BMPs active in 2009 were assessed as those within their respective design practice life, and in certain instances, using best professional judgment.

SWCD and NRCS data were summarized individually for each sub-watershed. These BMPs were then cross-walked with the Chesapeake Bay Program's BMP Short Names to enable assignment of appropriate load reductions or reduction efficiencies. NRCS data only included those BMPs not receiving SWCD cost-sharing, in order to avoid double-counting practices.

BMPs involving land use changes were simulated as acreages and load reductions from the former land use and as acreage and load increases in the new land use. Load reductions by land use were summarized as passthru factors. State SL-6 and CRSL-6 practices were simulated as having land use change, filtering effect, and rotational grazing components; state LE-2 and WP-2 practices had both a land use change and a filtering component. Rotational grazing acres were calculated as the Area Benefitted minus (fencing length x buffer width) / 43,560. Efficiencies for filtering practices were applied to 2x the buffer acreage for sediment and 4x the buffer acreage for nitrogen.

The BMP data from the Shenandoah Valley SWCD is summarized in Table G-1, and from NRCS in Table G-2. Table G-3 shows a summary of the land use changes and passthru factors used to represent the BMPs in Long Meadow Run and Turley Creek watersheds.

Table G-1. Summary of DCR Cost-shared BMPs, Active in 2009

DCR Code	BMP Short Name	Units	Long Meadow			Turley Creek			Long Meadow Run Total	Turley Creek Total	N eff%	P eff%	Sed eff%
			LOM-1	LOM-2	LOM-3	TRL-1	TRL-2	TRL-3					
CRFR-3	ForestBuffers	Acres	0	5.1	0	0	0	0	**5.1**	**-**	34	30	40
SL-1	LandRetireHyo	Acres	0	160.5	0	0	6	0	**160.5**	**6.0**	0	0	0
SL-6	PrecRotGrazing	Acres		176.15	126.93	0.00	0.00	0.00	**303.1**	**-**	24	30	40
	PastFence	Lin. Feet	0	5410.5	2198	0	0	0	**7,608.5**	**-**			
SL-6B	OSWnoFence	Acres	0	1	0	0	0	0	**1.0**	**-**	5	8	10
SL-8B	CoverCropLOW	Acres	0	137.8	0	0	0	0	**137.8**	**-**	11	0	0
SL-8H	ComCovCropSOW	Acres	0	63.7	0	0	0	0	**63.7**	**-**	12	0	0
WP-2	PrecRotGrazing	Acres	0	50	0	0	0	0	**50.0**	**-**	24	30	40
WP-4	AWMS	Count	0	6	0	1	0	2	**6.0**	**3.0**	Load reduction		
WP-4C	MortalityComp	Count	0	2	0	1	0	1	**2.0**	**2.0**	Load reduction		
WP-4B	LoafLot	Count	0	1	0	0	0	0	**1.0**	**-**	20	20	40

- These practices have multiple components: CRSL-6 and SL-6 include PrecRotGrazing, LU change, and filtering; LE-2 and WP-2 include LU change and filtering.

Table G-2. Summary of NRCS BMPs w/o DCR Cost-sharing, Active in 2009

NRCS Code	BMP Short Name	Units	Long Meadow			Turley Creek			Long Meadow	Turley Creek	N eff%	P eff%	Sed eff%
			LOM-1	LOM-2	LOM-3	TRL-1	TRL-2	TRL-3					
313	AWMS	no	0	3	0	0	0	1	**3.0**	**1.0**	Load reduction		
317	MortalityComp	no	0	2	0	0	0	1	**2.0**	**1.0**	Load reduction		
382	GrassBuffers	ft	0	6544	0	0	0	0	**6,544.0**	**-**	24	30	40
391	ForestBuffers	ac	0	4	0	0	0	0	**4.0**	**-**	34	30	40
561	LoafLot	ac	0	0.4	0	0	0	0	**0.4**	**-**	20	20	40
580	NonUrbStrmRest	ft	0	3000	0	0	0	0	**3,000.0**	**-**	Load reduction		
590	EnhancedNM	ac	0	52.4	0	0	0	0	**52.4**	**-**	7	0	0
528	PrecRotGrazing	ac	0	177.5	0	0	0	0	**177.5**	**-**	9	24	30
528A	PrecRotGrazing	ac	0	32.9	0	0	0	0	**32.9**	**-**	9	24	30
612	TreePlant	ac	0	4	0	0	0	0	**4.0**	**-**	0	0	0
614	OSWnoFence	no	0	6	0	0	0	0	**6.0**	**-**	5	8	10
633	EnhancedNM	ac	0	82.1	0	0	0	6.4	**82.1**	**6.4**	7	0	0

- These practices have multiple components: both onsite reductions, and filtering.

Table G-3. Summary of Combined Land Use Change and Passthru Factors used to Represent BMPs Active in 2009

Land Use/Source	Long Meadow Run			Turley Creek		
	LU Change (acres)	Sediment passthru	Nitrogen passthru	LU Change (acres)	Sediment passthru	Nitrogen passthru
cropland	-173.60	0.8231	0.7948	-6.00	0.9735	0.9735
forest	13.10	1.0079	1.0079	0.00	1.0000	1.0000
trp	-11.41	0.8980	0.8980	0.00	1.0000	1.0000
hyo	171.91	1.2094	1.2094	6.00	1.0198	1.0198
pasture excl trp and afo	0.00	0.9699	0.9907	0.00	1.0000	1.0000
afo	0.00	0.9865	0.9933	0.00	1.0000	1.0000
channel (ft)	3000.00			0		

Appendix H: Calibration Procedures for Nitrogen

Observed baseflow rates, spring N concentrations, and in-stream N concentrations were used to inform the calibration of nitrogen for the Long Meadow Run watershed. A limited number of observed baseflow rate measurements were made at USGS station 01632367 on Long Meadow Run at Route 793, which ranged from 0.66 – 4.04 cfs on 11 dates from 2008 – 2012. High nitrates in springs were verified with 2 samples at the spring located at station 1BLOM002.21 of 8.26 and 8.32 mg/L, and one sample at the spring located at 1BLOM007.36 of 8.27 mg/L. In-stream monitoring at 1BLOM001.45 (same location as USGS 01632367) averaged around 7.5 mg/L total nitrogen, as averaged from 52 samples, ranging from 5.57 – 8.74 mg/L.

Preliminary calibration in Long Meadow Run was effected through adjustments in 3 parameters: the groundwater N loading factor (N_GW), the seepage coefficient (SeepCoef), and the sediment-attached N loading factor (N_SED).

A procedure was then needed for transferring the adjustments for these three parameters to the comparison watersheds. Since the comparison watersheds are not known to be losing streams as Long Meadow Run is, the same exact adjustments did not seem appropriate. In order to establish a basis for transfer of these adjustments, a brief review of some literature and DEQ monitoring data that was readily available from other watershed studies was performed and the following rationale developed.

A USGS NAWQA Fact Sheet (#161-95) summarized information from nitrate measurements taken from sub-watersheds throughout the Great Valley carbonate subunit of the Potomac River Basin after classifying sites by dominant land use as cropland, pasture, and forest. The average concentrations in the Virginia portion of this subunit were 6.6, 2.6, and 1.44 mg/L nitrate-nitrogen for cropland, pasture, and forest, respectively. The comparison and TMDL watersheds were then visually categorized as being either carbonate or non-carbonate from a GIS overlay of the watershed boundaries and hydrogeomorphic regions as in Table H-1. Additionally, the BSE archives were searched for past DEQ monitoring data that was available for any of these watersheds. Average values from this search are also included in the same table.

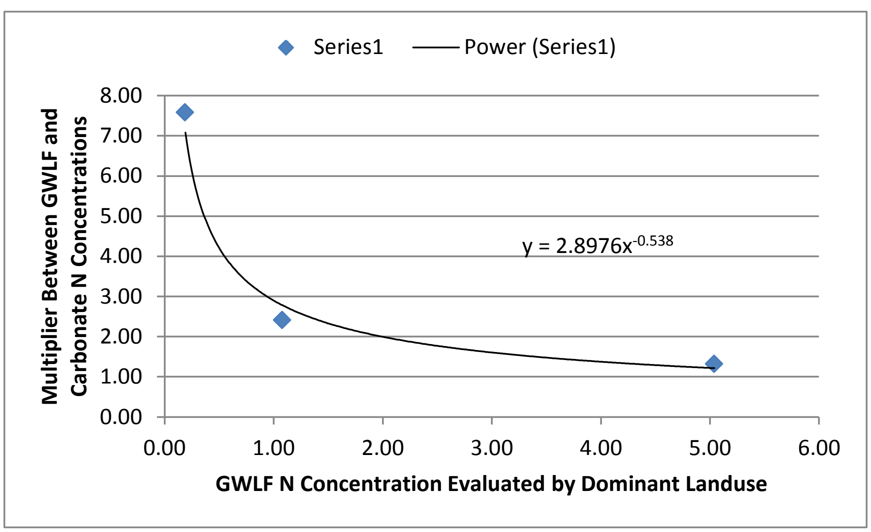
Table H-1. Categorized Watersheds and average monitored N concentrations

Carbonate		Non-carbonate	
CODE	**TNave (mg/L)**	**CODE**	**TNave (mg/L)**
LOM	7.50	NTH	1.53
TRL	3.00	BVR	1.04
MFT		MIL	2.00
LEW	4.30	LAR	
BRO	2.20	LSC	
CUB		CDR	
NAK	2.27		

While this is not a definitive sample, it corroborates the generally higher N values in the carbonate watersheds, and provides a basis for transferring the adjustments in Long Meadow Run to the other watersheds.

The average categorized USGS concentrations were then contrasted with the concentrations for these land uses evaluated from the GWLF user manual (Haith et al., 1992), which for contrast I label “non-carbonate”. The values from GWLF in the Eastern US for >90% agriculture, >50% agriculture, and >90% forest, which roughly correspond to the dominant land uses above were 5.04, 1.08, and 0.19 mg/L dissolved nitrogen, respectively. Multipliers were calculated between the USGS and GWLF concentrations for these three points and an equation created that represented a power relationship between the multipliers and the GWLF concentrations, producing a transfer function to more appropriately represent N_GW for the carbonate watersheds. The non-linear regression derived from this data was $2.8976 * N\_GW^{-0.538}$, as shown in Figure H-1.

Figure H-1. Groundwater Nitrogen Transfer Function for Carbonate Watersheds



The SeepCoef was adjusted to 0.80 in Long Meadow Run in order to match observed baseflow rates, while all other watersheds used a SeepCoef value of 0.05. In addition to the transfer function for carbonate watersheds, N_GW was further adjusted through a uniform multiplier of 1.3 applied to all watersheds to achieve the average groundwater N concentration of 8 mg/L in Long Meadow Run. NSED already showed a differentiation between carbonate and noncarbonated areas in the GWLF guidance, so a uniform multiplier of 1.5 was applied to NSED in order to achieve the average in-stream N concentration of 7 mg/L.

The final calibrated average flow rate in Long Meadow Run was 3.35 cfs, the average N baseflow concentration was 8.0 mg/L, and the average in-stream N concentration was 7.0 mg/L. The calibrated parameter values are given in Appendix E.

Appendix I: Groundwater N Distribution to Landuses

Although groundwater was initially simulated as a separate source to emphasize its important contribution to stream nitrogen loads, in reality the nitrogen in groundwater arises from management associated with individual landuses, and can best be reduced through improved management practices on those landuses. In order to make this link more explicit, the groundwater nitrogen load was distributed among the pervious landuses in the Long Meadow Run watershed. While the GWLF model uses a loading function to calculate loading to groundwater from various landuses, it also assigns a general nitrogen concentration to the groundwater pool, making it difficult to distribute this rationally among landuses. The Phase 5.3.2 Chesapeake Bay Watershed Model (CBWM) uses more explicit algorithms to simulate dissolved and particulate (organic) forms of nitrogen, using the dissolved nitrogen (NO23) and particulate nitrogen (OrgN) parameters and output from the CBWM for the A51165PS2_5560_5100 land-river segment that encompasses Long Meadow Run was used as the basis for this distribution. Although the assumption was made that the entire dissolved load originates from groundwater may be somewhat simplistic, it appears to be a reasonable means of distributing groundwater N among the various landuses.

The data in Table I-1 were extracted and summarized for edge-of-stream (eos) loads from a progress 2010 run of the model for land-river segment A51165PS2_5560_5100. Although Total N includes NH3X, it will most likely be in the form of a gas, so it was omitted for the purpose of developed surrogate ratios of subsurface N loads to surface N loads (assumed to be particulate). The calculated ratios are in the far right column of Table I-1.

Table I-1. CBWM Phase 5.3.2 eos Loads for N Components, A51165PS2_5560_5100

CBWM LU Code	CBWM Landuse Categories	NH3X	NO23	OrgN	TOTN	NO23/OrgN Ratio
		(lbs/year)				
septic	septic	0.0	51,253.2	0.0	51,253.2	#DIV/0!
for	forest	13,008.9	74,432.8	98,237.0	185,678.8	0.76
hvf	harvested forest	694.3	12,539.3	3,566.6	16,800.2	3.52
hwm	high-till with manure	18,577.3	206,060.9	143,662.7	368,301.0	1.43
lwm	low-till with manure	44,916.8	577,059.9	469,651.6	1,091,628.0	1.23
hom	high-till without manure	2,809.2	30,292.5	5,809.4	38,911.0	5.21
alf	alfalfa	4,595.5	123,669.6	13,848.7	142,113.9	8.93
hyw	hay with nutrients	27,130.0	206,694.3	75,240.7	309,065.0	2.75
hyo	hay without nutrients	1,549.8	28,784.1	5,367.7	35,701.6	5.36
pas	pasture	45,383.6	612,765.1	167,083.7	825,232.4	3.67
trp	pasture corridor	75,946.1	73,864.9	54,749.5	204,560.5	1.35
urs	nursery	1,179.3	15,938.2	2,346.6	19,464.1	6.79
nhi	high-till with manure nutrient management	6,444.8	62,623.6	40,099.4	109,167.8	1.56
nlo	low-till with manure nutrient management	15,603.0	170,866.5	114,647.6	301,117.0	1.49
nho	high-till without manure nutrient management	1,333.6	14,109.6	2,773.9	18,217.2	5.09
nal	alfalfa nutrient management	0.0	0.0	0.0	0.0	#DIV/0!
nhy	hay with nutrients nutrient management	16,287.6	124,381.9	45,356.7	186,026.2	2.74
npa	pasture nutrient management	7,859.1	102,659.9	34,252.5	144,771.4	3.00
rpd	regulated pervious developed	110.0	1,447.1	2,109.0	3,666.2	0.69
npd	nonregulated pervious developed	5,543.1	72,892.6	106,233.2	184,668.9	0.69
cpd	CSS pervious developed	0.0	0.0	0.0	0.0	#DIV/0!
rcn	regulated construction	232.0	2,853.8	4,185.3	7,271.0	0.68
ccn	CSS construction	0.0	0.0	0.0	0.0	#DIV/0!
rex	regulated extractive	0.0	0.0	0.0	0.0	#DIV/0!
nex	nonregulated extractive	1,239.3	16,407.2	2,452.7	20,099.3	6.69
cex	CSS extractive	0.0	0.0	0.0	0.0	#DIV/0!
afo	animal feeding operations	119,307.5	0.0	874,901.3	994,208.7	0
cfo	concentrated animal feeding operations	32,009.0	0.0	126,074.1	158,083.1	0
rid	regulated impervious developed	428.1	0.0	898.4	1,326.5	0
nid	nonregulated impervious developed	27,823.4	0.0	58,384.5	86,207.9	0

GWLF landuses were then associated with similar CBWM landuse categories and then assigned or averaged from multiple categories. The associated CBWM landuse categories are in the second column and the resulting ratios in the third column of Table I-2.

Table I-2. NO23/OrgN Ratios Calculated for GWLF Landuses

GWLF Landuses	Associated CBWM Landuse Categories	NO23/OrgN Ratio
HiTill Rowcrop (hit)	hwm, hom, nhi, nho	3.3242
LoTill Rowcrop (lot)	lwm, nlo	1.3595
Pasture (pas_g)	pas	3.6674
Pasture (pas_f)	pas, trp	2.5083
Pasture (pas_p)	trp	1.3491
Riparian pasture (trp)	trp	1.3491
AFO (afo)	afo	0.0000
Hay (hay)	hyw	2.7471
Forest (for)	for	0.7577
Harvested forest (hvf)	hvf	3.5158
Transitional (barren)	rcn	0.6819
Pervious LDI (pur_LDI)	rpd, npd	0.6862
Pervious MDI (pur_MDI)	rpd, npd	0.6862
Pervious HDI (pur_HDI)	rpd, npd	0.6862

From here the average annual groundwater N load was distributed to individual landuses on an area-weighted basis along with the NO23/OrgN ratios above using the formula:

$$GW\_N_{LU} = GW\_N * (Ratio_{LU} * Area_{LU}) / \Sigma(Ratio_{LU} * Area_{LU})$$

The resulting distributed groundwater loads by landuse summed up to equal the original groundwater load. The groundwater loads were then added to the usual GWLF loads to better represent the amount of nitrogen attributable to each landuse.